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16. Abstract (Limit: 200 words)

This paper summarized the construction and early performance assessment of three composite test cells at the MnROAD: Cell 70, HMA over a recycled aggregate concrete; Cell 71, diamond grind concrete over recycled aggregate concrete; and Cell 72, exposed aggregate concrete over a low cost concrete. The construction of cells 70, 71 and 72 was part of R21 Composite Pavement project of SHRP 2. Although composite pavement systems have become extremely popular in Europe, they are a relatively new concept to the United States. Strength, on board sound intensity, sound absorption, friction, texture and international roughness index were tested. Results suggest that the exposed aggregate concrete surface does not provide significant noise reduction. Innovative diamond grinding of composite pavements may be beneficial for noise reduction. Exposed aggregate surfacing can provide more than adequate friction for driver safety, but does not show any improvement from typical HMA or diamond ground surfaces. Exposed aggregate surfaces have a similar texture (or mean profile depth) to traditional diamond ground surfaces, but may detrimental to ride quality. Continued monitoring of these test cells will help develop the wide understanding of composite pavement performance needed for more effective design and accurate service life models.

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Composite Pavements at MnROAD:
Cells 70, 71 and 72 Construction Report and Early Performance Evaluation

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Table of Contents

List of Figures

List of Tables

INTRODUCTION TO COMPOSITE PAVEMENTS

Recent interest in pavement overlays as a rehabilitation method has led to a relatively high portion of the nations interstate system, both urban and rural, to be classified as composite pavement systems. However, other regions, specifically Europe and Canada, have been experimenting with constructing new pavements as composite pavement systems, a technique that can provide several benefits over single layer construction. These new composite pavement systems consist of two distinct layers. New composite pavement systems can be very economically effective, by using low cost materials, such as recycled or moderate quality aggregate, in the lower layer. The surface layer can then provide better performance characteristics, such as low noise characteristics, improved friction and ride characteristics, along with minimal maintenance, by utilizing new innovative pavement techniques. The lower layer of these composite systems is generally much thicker than the upper layer, further reducing costs by requiring less of the more expensive and durable materials. Composite pavements can be done using both asphalt concrete over new concrete, along with construction of two new concrete layers. In summary, composite pavement designs have the ability to provide long lasting, economical and environmentally sustainable transportation.

Many European countries have recognized the benefits of composite pavement and have practiced two-lift construction on a much larger scale than the United States. Belgium, the Netherlands, Switzerland, France and Germany have all been constructing composite pavements on a frequent basis since the 1980s. In Austria, the standard concrete pavement is designed and constructed according to their two-layer Portland Cement Concrete specification. [1] Besides concrete-on-concrete construction, the Netherlands has constructed asphalt over concrete composites on a multitude of new construction projects since 2000. Germany has used stone matrix asphalt over both continuously reinforced concrete pavement and jointed plain concrete pavement.

Although there are many different pavement types which are used on the lower and upper layers of composite pavements, one of the most common techniques is the use of exposed aggregate concrete (EAC) on the surface layer. This type of concrete utilizes very high quality aggregate.

The aggregate is exposed to the surface by applying a set retardant to the wet concrete surface and subsequently brushing off the surface mortar. Studies of different EAC in Europe found that aggregate size can vary from less than 1 mm up to 22 mm, but almost always found the best performance in pavements utilizing gap graded aggregate with size less than 8 mm.[1] Construction of two-lift pavements in Europe have varied over time. In the past, the two lifts were constructed using a single paver; however, recent construction is done using multiple pavers simultaneously. The term “wet-on-wet” construction refers to the accelerated construction method in which the second layer is placed immediately after the first to achieve a strong bond between the two layers. Finished exposed aggregate pavements are known for their noise reduction capability and increased durability and friction over conventional pavement surfacing techniques.

Multiple state DOT’s have become interested in promoting recycling, reducing pavement costs, achieving better surface characteristics and durability, and consequently, have started experimenting with two lift construction. However, despite this recent effort, the performance of composite pavements is not as clearly understood as it is for rigid and flexible pavements. Design of composite pavements has become hindered by the lack of performance models, service life predictions, and life-cycle cost analysis. More performance data is needed for effective design of composite pavements, along with better construction specifications and guidelines.

PROJECT OVERVIEW AND DESIGN

As discussed in the previous section, composite pavements are becoming increasingly popular in Europe. Consequently, many states have been experimenting and evaluating the prospect for utilizing the technique in the United States. In 2005, Congress established the second Strategic Highway Research Program (SHRP 2). This program was created to conduct research focused on four areas highway transportation: safety, renewal, reliability and capacity. SHRP 2 will receive four years of funding and is set to be complete by 2013. Part of the SHRP 2 Program is the Composite Pavement Systems R21 project aimed at developing and providing strategies for rapid renewal of the national highway system [2]. Unlike pavement overlays commonly used as a method of rehabilitation, composite pavements are designed and constructed as a new pavement system. Composite pavements consist of two different pavement layers, with a low quality or recycled base layer, and a high quality top layer that provides a better wear surface.

Overview

Cells 70, 71 and 72 at the MnROAD research facility were constructed as part of the SHRP 2-R21 project to evaluate two different types of composite pavements: an asphalt layer over a PCC layer and a high surface quality PCC layer over a lower quality PCC layer. MnROAD consists of two distinct segments of roadway, the Mainline, a segment of Interstate 94, and the Low Volume Road. There are a total of 50 test cells between the Mainline and Low Volume Road, each with a distinct pavement type and design. Maps of the mainline and Low Volume Road that include descriptions of each cell will be provided in Appendix A of this report. The three composite pavement test cells discussed in this report are all located on the Mainline.

This project will the serve the following three main objectives:

- Establish important material parameters of these particular composite pavements, and identify their behavior and performance characteristics.
- Work to develop mechanistic-empirical performance models for composite pavements that can be used as a design method in the Mechanistic-Empirical Pavement Design Guide (MEPDG).
- Determine recommendations for construction specifications, techniques and other quality management procedures [3].

Cell Design

The top layer of cell 70 is high quality hot mix asphalt (HMA). An exposed aggregate concrete (EAC) mix is used as the top layer of cells 71 and 72. The bottom layer of cells 70 and 71 is concrete utilizing 50% recycled concrete aggregate (RCC). The bottom layer of cell 72 will consist of an economical "Low Cost" mix (CHP) that utilizes a relaxed aggregate gradation. Figure 1 below shows a cross section of the three composite cells along with the aggregate base designations. Although the mix composition changes from cell to cell, the depths of each pavement layer, base, and subgrade remain the same. All cells were constructed with 15 foot panels. Cells 71 and 72 have 1 inch dowels throughout both lanes, where Cell 70 has 1 inch dowels in the driving lane only. More material properties and cost information for the three different mix types are specified in tables 1 and 2 below.

Cell 70	Cell 71	Cell 72
3" HMA	3" EAC	3" EAC
6" RCC	6" RCC	6" CHP
8" Class 5	8" Class 6	8" Class 7
Clay	Clay	Clay

Figure 1: Cell Composition

Table 1: Mix Summary

Mix Designation	Pavement Location	Fly Ash	Aggregate
EAC	Upper "Wear"	15 %	98% passing 3/8 in.
CHP	Lower	60 %	Relaxed Gradation
RCC	Lower	40 %	50% Coarse Aggregate from RCA

Table 2: Cost

Mix Designation	Qty.	Cost	
EAC	255.0 CY	$175/CY	3059 SY @$48/SY
CHP	255.0 CY	$140/CY	4323 SY @$30/SY
RCC	466.0 CY	$135/CY	

Figure 2 illustrates the differences in aggregate gradation for the three mixes, and tables 3, 4 and 5 provide material information and complete mix designs. The complete mix designs and aggregate gradations are provided in Appendix B of this report.

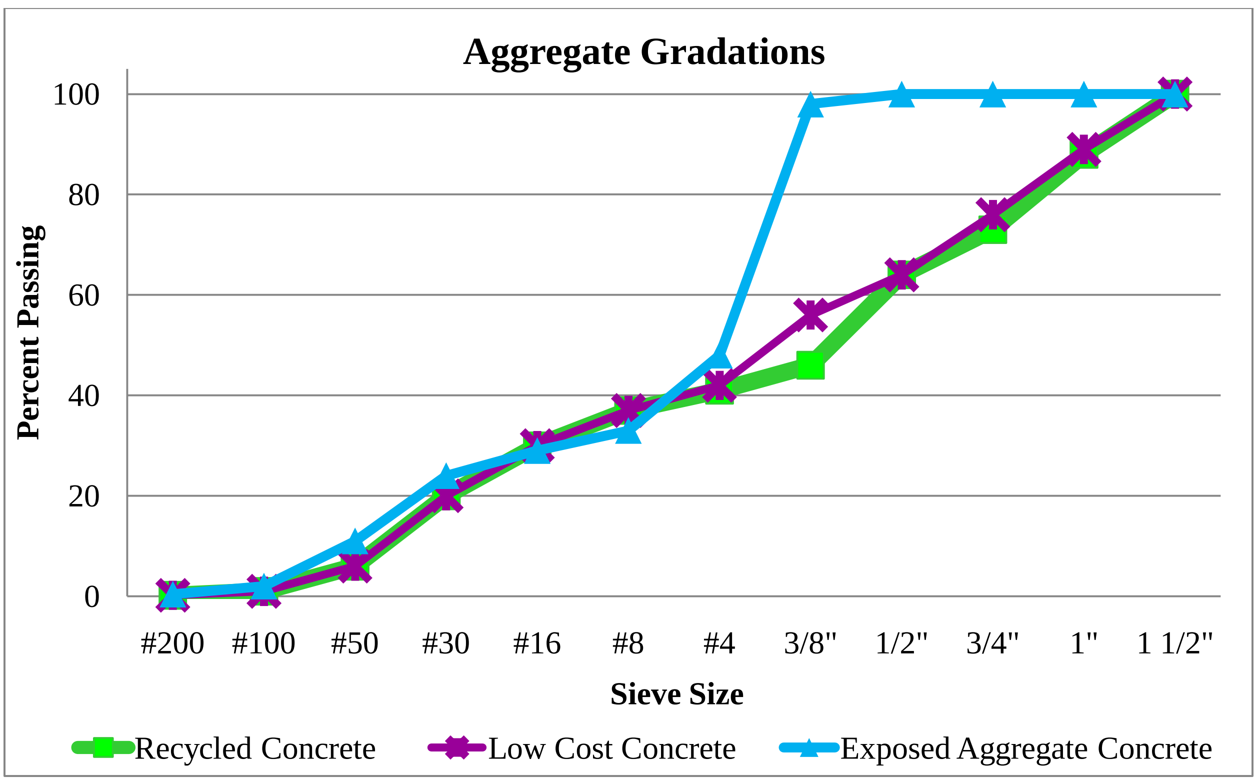

Figure 2: Aggregate Gradations

Figure 2 illustrates the unique gradation of the exposed aggregate mixture, with close to 50% falling between the 3/8 inch and #4 sieve size. This gradation is designed to produce a surface texture with good friction characteristics and reduced noise generation. The gradation of the low cost mix and recycled mix are fairly similar, with the only significant difference being a slightly coarser gradation in the low cost mix.

Table 3: Material Information

Recycled Concrete Aggregate						
	CA1		**CA2**		**Sand**	
Pit Name	Agg. Ind		McCrossan		Agg. Ind	
Town	Elk River		Maple Grove		Elk River	
Size	#4 (1 - 1/2 ")		Recycle		C. Sand	
SG and Abs	2.75	0.90%	2.49	2.93%	2.63	0.90%
Low Cost						
	CA1		**CA2**		**Sand**	
Pit Name	Agg. Ind.		Agg. Ind.		Agg. Ind	
Town	Elk River		Elk River		Elk River	
Size	#4 (1 - 1/2 ")		#67 (3/4" -)		C. Sand	
SG and Abs	2.75	0.90%	2.69	1.30%	2.63	0.90%
Exposed Aggregate						
	CA1		**CA2**		**Sand**	
Pit Name	Marietta		Marietta		Agg. Ind	
Town	St. Cloud		St. Cloud		Elk River	
Size	1/2" W. Chips		3/8" W. Chips		C. Sand	
SG and Abs	2.72	0.40%	2.72	0.40%	2.63	0.90%

Table 4: Cement and Fly Ash

All Mixes		
	Cement	**Fly Ash**
Manufacturer	Holcim	Headwaters
Mill/Power Plant	STGBLMO	COCUNND
Type/Class	I/II	C/F
SG	3.15	2.5

Table 5: Mix Designs

	Recycled	**Low Cost**	**Exposed Aggregate**
Water (lbs/cy)	234	172	283
Cement (lbs/cy)	360	240	616
Fly Ash (lbs/cy)	240	360	109
W/CM	0.39	0.29	0.39
Sand (OD lbs/cy)	1200	1263	843
CA1 (OD lbs/cy)	825	787	1133
CA2 (OD lbs/cy)	920	1102	843
Max Slump (in)	3	3	3
% Air	7	7	7
Multi-Air 25 (oz/cy)	2 - 15	2 - 15	2 - 15
Sike 686 (oz/cwt)	1 - 7	1 - 5	1 - 5
Admixture 3	0-30 oz/cwt Sikaset NC (non-chloride accelerator)	0-30 oz/cwt Sikaset NC (non-chloride accelerator)	0-5 oz/cwt Delvo as needed for slump retentions

The exposed aggregate concrete mix is an extremely rich mixture with more than 600 lbs of cement and 725 lbs of total cementitious material per cubic yard. However, the low cost and recycled aggregate mix only contains a total cementitous content of 600 lbs per cubic yard. This difference between the two mixes is a result of the fly ash content. The low cost mix uses a high class F fly ash content of 360 lbs per cubic yard, where the recycled mix only has 240 lbs per cubic yard. However, the total cementitious content of both the CHP and RCC mixtures was 600lbs per cubic yard. The sources for fine aggregate, cement and fly ash are the same for all three mixes.

Although both cells 71 and 72 were constructed using the high quality exposed aggregate mix in the top layer, three different surface treatments were used to evaluate a broader range of pavement types. Cell 71 was finished with diamond grinding, with an innovative diamond grind in the driving lane and the traditional diamond grind in the passing lane. Cell 72 will be treated using common practices for exposed aggregate finishes, by applying a set retarder to the surface. The set retarder used was MBT Reveal, a water based compound produced by BASF Admixture Systems. This chemical provides etch retention and consistency in temperatures up to 130° F and for up to sixteen hours. [4] MBT Reveal is both odorless and non-flameable. It does not require the use of plastic covers which minimizes the required application labor. This compound allows the unhardened surface mortar to be removed by brushing to reveal the aggregate to the surface.

A practice demo slab was constructed in the stockpile area of the MnROAD test facility. This slab consists of a 100 foot section of recycled concrete mix and a 100 foot section using the low cost concrete. The exposed aggregate mix and surface finish will be used as the top layer of the composite throughout both sections. It will be placed on the existing granular grade, with 15 foot panels and 1 inch dowels throughout.

Instrumentation

All three composite cells were equipped with the necessary instrumentation for monitoring humidity, temperature and strain over time. This instrumentation is described in table 6 below.

Table 6: Instrumentation Description

Sensor	Code	Quantity			Description
		Cell 70	Cell 71	Cell 72	
Concrete Embedment Strain Gauge	CE	26	56	56	Tokyo Sokki, PML-60-20LTSB, with 20 meters of 3-wire lead
Vibrating Wire Strain Gauge	VW	20	30	30	Geokon, 4200A-2, with 02-187V3-E red PVC cable with two twisted pairs
Humidity Sensor	MC	42	42	42	Sensirion, SHT75, Humidity/Temp Sensor PIN +/-1.8% (RoHS compliant)
Thermocouple	TC	72	72	72	Omega, 8TX20PP, Type TX Thermocouple Cable, 20 AWG single strand conductors

The vibrating wire strain gauge measures strain in the pavement due to material shrinkage and environmental factors. The concrete embedment strain gauge measures the pavement response to dynamic loads. The strain gauges were placed at different depths within the concrete pavement layers. The humidity and temperature (thermocouple) sensors were placed at different depths throughout the pavement, base, and subgrade using MnROAD designed sensor trees. The general instrumentation layout is shown in Figures 3 and 4 below.

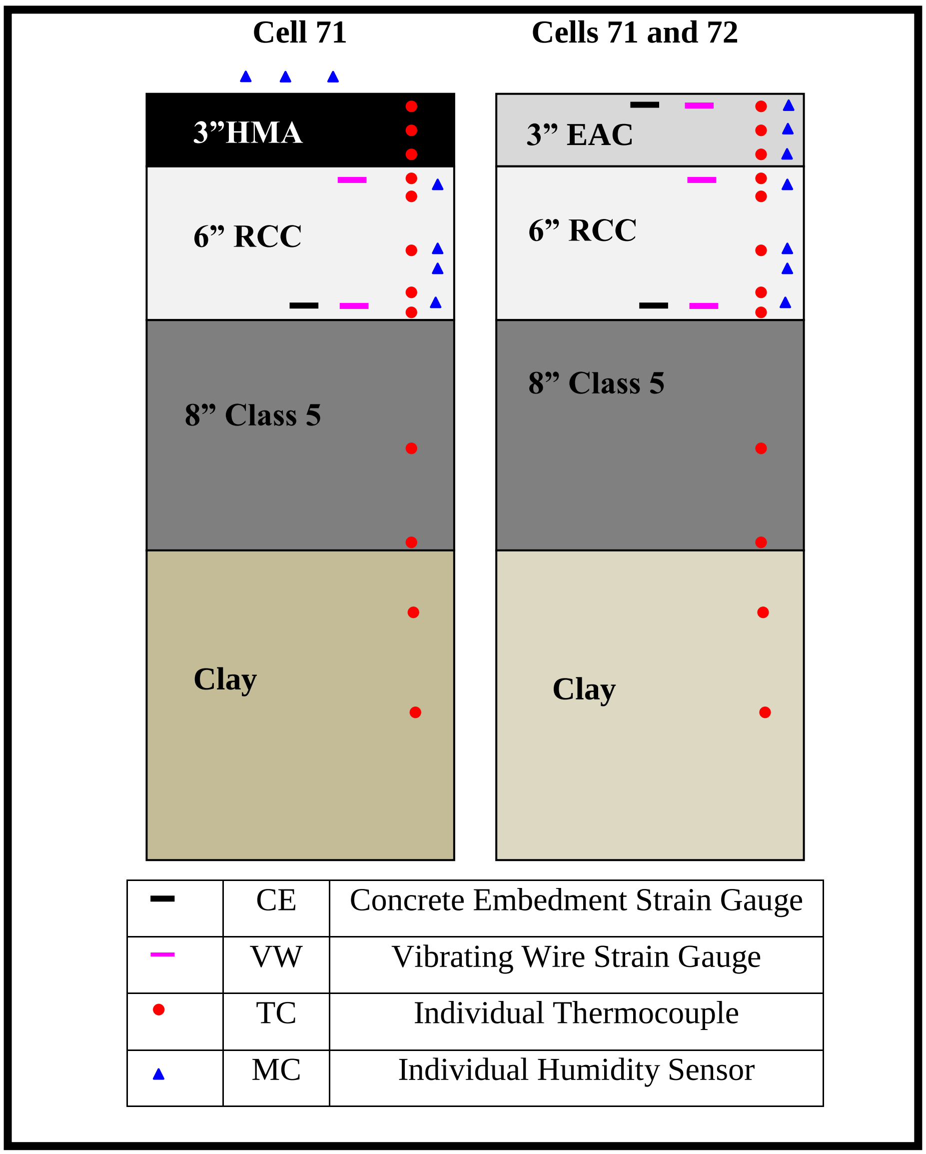

Figure 3: Instrumentation Layout Cross-section

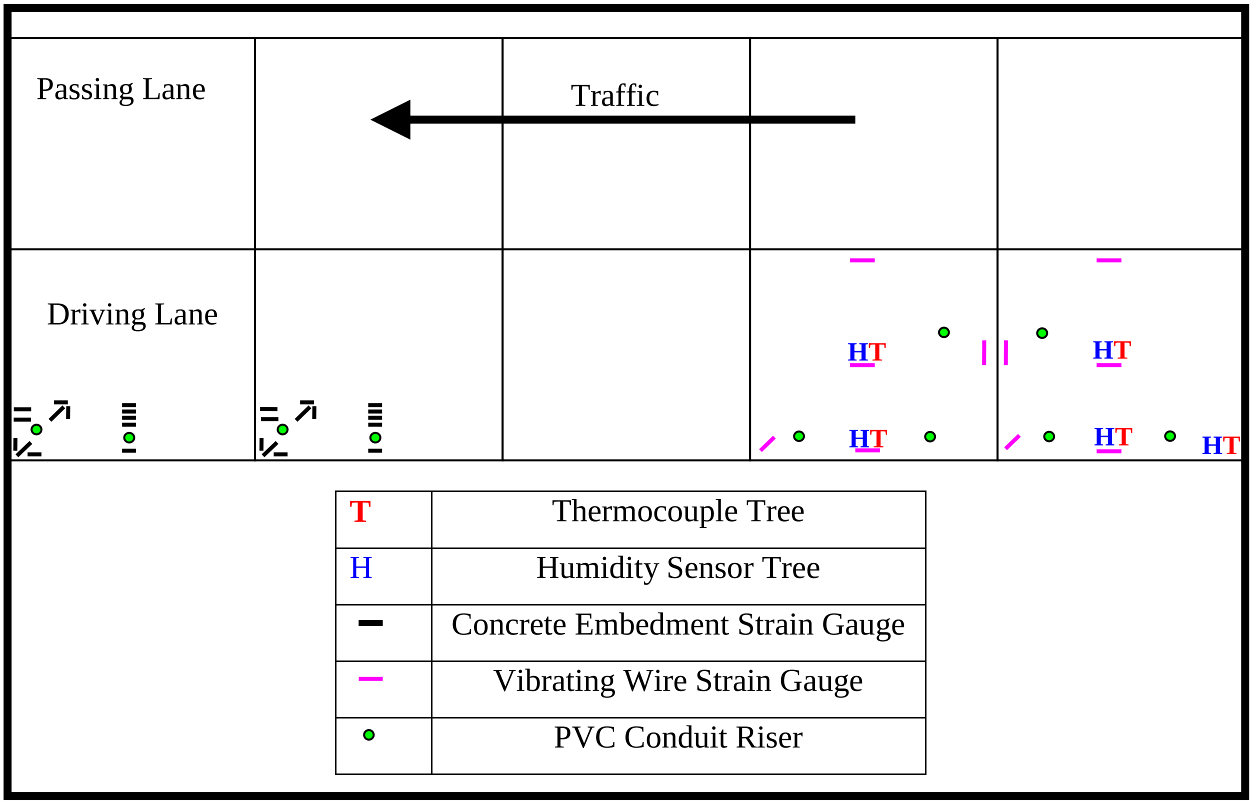

Figure 4: Instrumentation Layout – Cell 70

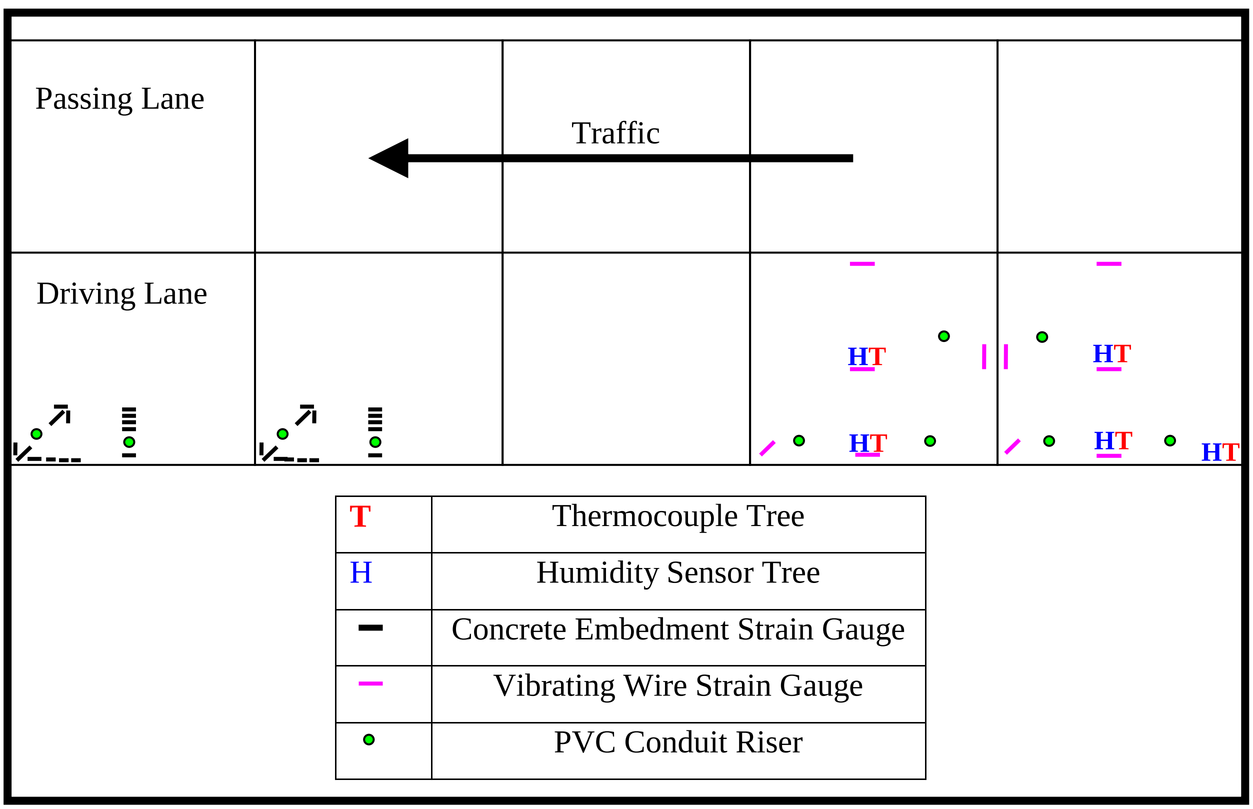

Figure 5: Instrumentation Layout – Cells 71 and 72

CONSTRUCTION SEQUENCE

The following chapter summarizes the preparation and construction of the three composite cells and demo slab at MnROAD. The construction contract for cells 70, 71 and 72 was awarded to CS McCrossan, Inc. (CSM) and was administered and inspected by WSB and Associates.

Mainline Pre-Construction and Demo Slab Paving

Construction of the three composite cells at MnROAD officially began on Monday April 12th, 2010 when the top soil of all three cells was stripped. The top soil berm was to be used for erosion control. The previously in place bituminous shoulders were milled to be used as reclaimed asphalt pavement by CSM. The existing concrete pavement in cells 70, 71 and 72 was broken, removed and hauled back to CSM to be crushed and used in the new first layer of the composite cells 70 and 71.

Figure 6: PCC Removal

During the week of April 19th to the 23rd, the subgrade of cells 70, 71 and 72 was trimmed with a trimming machine and compacted with a steel drum roller. The subgrade was ramped with class 3 and 5 aggregate base. Mn/DOT researchers collected samples and performed lightweight deflectometer, falling weight deflectometer and dynamic cone penetrometer testing. The class 5 aggregate base was constructed in two four inch lifts. Mn/DOT researchers placed metallic plates on top of the compacted subgrade and sensor conduits were installed throughout the base layers. Also during this week, the removed PCC was crushed at CSM to be used as recycled aggregate.

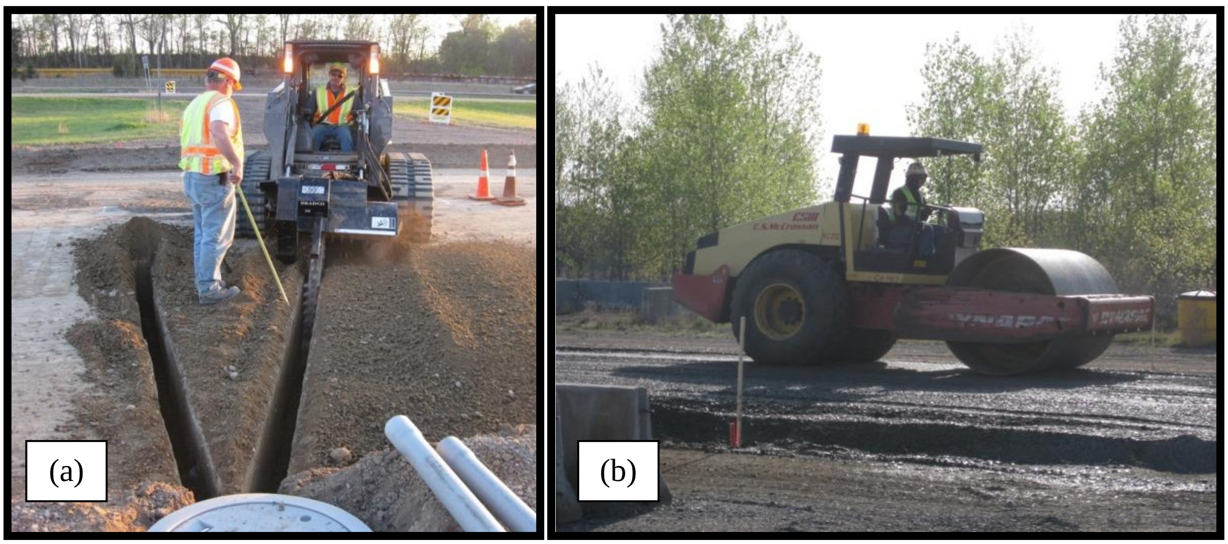

Figure 7: (a) Sensor Conduit Installation and (b) Subgrade Compaction

During the week of April 26th to April 30th before paving the new composite cells, work was done to prepare a demo composite pavement slab. The slab was to be 200 feet in length and was constructed in the stockpile area of the MnROAD research facility. 100 feet of the demo slab was paved using the low cost PCC mix, and the remaining 100 feet was done using the recycled concrete mix. Crews experienced issues with the workability and consistency of the recycled PCC mix. The slowed delivery was expected to influence the degree of bonding between the two layers. However, the issues seemed to be resolved near the end of the slab. The contractor initially experimented with the low cost mix. The first few batches were sent away for being too wet, but adjustments were made in subsequent batches to achieve the desired consistency. The top layer of the entire slab was paved using the exposed aggregate mix. This mix seemed to achieve the necessary properties for placement and finishing.

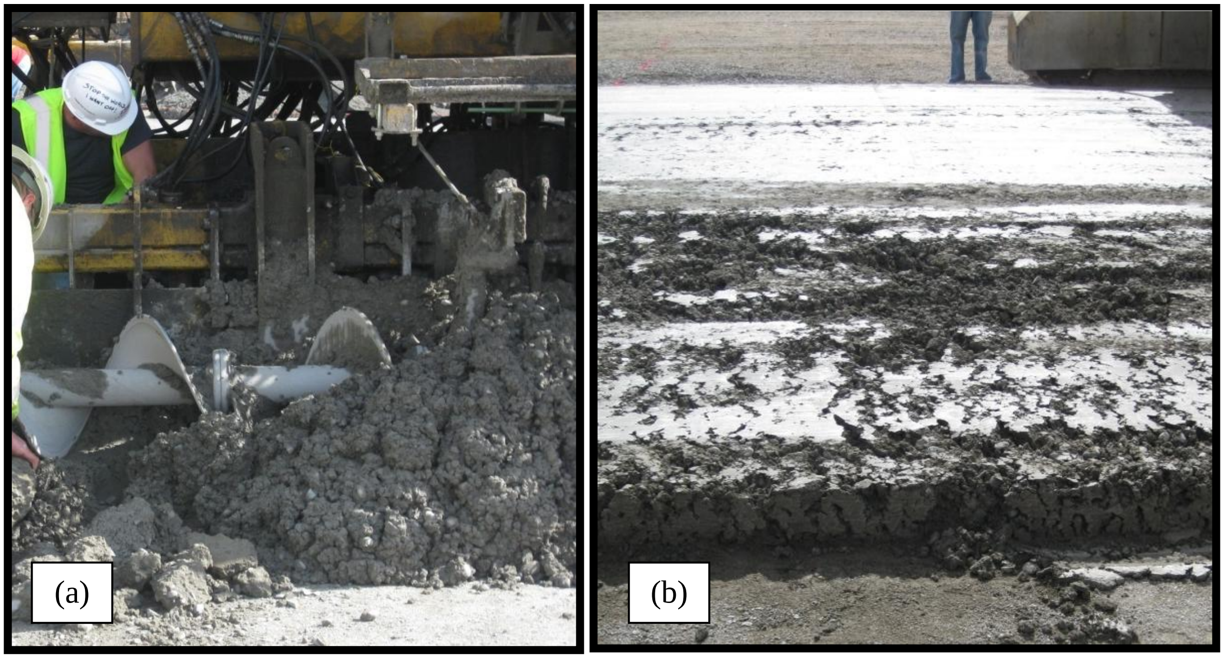

Figure 8: (a) Demo Slab Construction and (b) Demo Slab Bottom Lift

Figure 9: Demo Slab Construction

Figure 10: Demo Slab Finished Surface

After paving the demo slab, MnROAD and University of Minnesota personnel continued work on preparation of the aggregate base, sensor layout, and sensor installation for the three test cells.

Mainline Paving Construction

Paving of the composite cells on the Mainline of MnROAD began on May 5th 2010 with cell 70. This cell was 474 feet in length, with the first composite layer consisting of 6 inches of recycled concrete aggregate concrete (RCC) and a 3 inch top composite layer of hot mix asphalt (HMA). The RCC was placed on May 5th. The HMA was to be placed over the hardened concrete on a subsequent date. The first few batches of RCC experienced some problems with consistency and air content compared the RCC used in the demo slab, with more desirable workability and a slump near 1.5 to 1.75 inches, allowing foot traffic after only 45 minutes. The table below shows the slump and air content of the RCC over the duration of paving.

Table 7: Cell 70 Fresh Concrete Testing

Mix	Time	Slump (in)	Air Content (%)
RCC	7:30 am	0.75	7.0
RCC	7:50 am	1.5	10.8
RCC	8:15 am	-	10.6
RCC	9:07 am	3.25	8.5
RCC	9:43 am	1.5	6.8
RCC	10:55 am	1.75	6.8

It began raining during the afternoon of paving cell 70. However, paving finished fifteen minutes after the rain began, and the entire cell was covered with poly another thirty minutes later.

9


Figure 11: MnROAD Mainline Cell 70 – Lower Lift Construction

Paving of cell 71 began on Thursday May 6th. There was a shortage of recycled aggregate concrete due to a 40% loss of the old PCC during washing and two loads of RCC being rejected for high slump. Consequently, cell 71 only reached 266 feet in length. The paving, however, did not encounter any other issues in either the RCC or 3 inch layer of exposed aggregate concrete (EAC). The first load of RCC was poured by 7:56 am, and the last load was poured by 10:24 am. The first load of EAC was poured by 8:23 am and the last load by 11:22 am. The time between the two lifts varied between approximately 30 minutes to an hour while paving. The RCC achieved better slump and consistency than the demo slab. Table 2 shows the air content and slump of both the RCC and EAC in cell 71.

Table 8: Cell 71 Fresh Concrete Testing

Mix	Time	Slump (in)	Air Content (%)
RCC	8:10 am	1.25	6.6
EAC	9:10 am	2.25	5
EAC	9:20 am	2.25	6.2

Figure 12: MnROAD Mainlne Cell 71 Construction

The paving of cell 72 was scheduled for Friday, May 7th; however rain forced a rescheduled date of Monday, May 10th. Cell 72 was constructed to be 681 feet long, accounting for the 208 feet which were not paved in cell 71. Once again, this cell consists of a 6 inch layer of low cost concrete mix (CHP) and a wet-on-wet 3 inch overlay of exposed aggregate concrete (EAC). Paving encountered multiple obstacles throughout the day. Three loads of concrete were rejected, two by the contractor and one by Mn/DOT. The first load of low cost concrete was poured by 8:13 am, and the last load at 3:18 pm. The first load of top lift EAC was poured by 9:15 am, and the last load around 3:55 pm. Similar to cell 71, the time between paving the top and bottom lifts varied between thirty minutes to over one hour as paving progressed. It began raining 15 minutes after the last load had arrived. The surface was treated with a MBT Reveal, a water-based top surface retarder intended for exposed aggregate concrete. After brushing of the cell to expose the aggregate surface, the slab was covered with poly. Because of the complications from rain and low temperature, there were some difficulties in brushing of the surface. Table 3 below shows the slump and air content of the low cost concrete and the exposed aggregate concrete mixes.

Table 9: Cell 72 Fresh Concrete Testing

Mix	Time	Slump (in)	Air Content (%)
CHP	8:23 am	2.75	7.2
CHP	9:33 am	2.5	6.4
EAC	10:14 am	3.25	5.7
EAC	10:55 am	2.0	9.0
EAC	11:12 am	2.5	7.5


(a) (b)

Figure 13: (a) Fresh Concrete Testing and (b) MnROAD Mainline Cell 72 Construction

Figure 14: MnROAD Mainline Cell 72 Construction

The morning of the day after paving of cell 72, the surface of the remaining sections were brushed. This effort was much more successful at achieving the desired texture than the previous day. The poly was removed from the cell. It rained on site after paving had been completed.

Figure 15: MnROAD Mainline Cell 72 Brushing (1)

Figure 16: MnROAD Cell 72 Brushing (2)

On Wednesday, May 12, Mn/DOT mix and repair procedures were used to repair the spalled concrete and a corner break on cell 70 and a curing compound was applied to the slab. On Thursday, May 20th, the shoulders were prepared for a class 2 aggregate, the bituminous tack coat was placed on the concrete surface, and the paving of the HMA layer of cell 70 was completed. This bituminous paving was done in two lifts. Over the next week, she second lift of shoulders was placed, joints were sawed and sealed in the HMA in cell 70, and the aggregate shoulders were placed and tack sealed.

Figure 17: (a) through (d) MnROAD Mainline Cell 70 - Top Lift Construction

On Tuesday, May 25th, the passing lane in cell 71 was ground using the conventional diamond grind. The innovative diamond grind of the driving lane in cell 72 was completed on the 27th. The final sweeping of the project was done on Friday, May 28th.

The week after paving had been completed was used for initial testing and evaluation. Cells 70, 71 and 72 on the Mainline were officially opened to traffic on Monday June 7th. Periodic lane closures were used to monitor the performance of the composite cells. Results from this evaluation will be discussed in the next chapter.

Time Lag between Lifts

The time between paving the first lift and second lift of "wet-on-wet" composite pavements is an important factor influencing the bond between the two layers. Although data is not available for the actual time lag between the two pavers during construction of cells 71 and 72, the truck arrival time taken from the contractor's batch tickets can be used as a reasonable estimate for the time paving began. Each truck of bottom lift and top lift concrete delivered approximately 8 cubic yards of material. Because each cell is 27 feet wide (a 14 ft driving lane and 13 ft passing lane), each load can pave approximately 16 longitudinal feet of bottom lift concrete and 32 longitudinal feet of top lift concrete. Using this information, the time lags between lifts have been estimated in the tables below and plotted in figure 18. The rejected truck loads were not included in the calculations for the amount of material delivered.

Table 11: Time Lag Between Lifts – Cell 71

Feet Delivered	Time of Arrival		Paving Lag
	RCC	EAC	
16	7:56		
32	8:05	8:23	0:18
48	8:10		
64	8:12	9:10	0:58
80	8:15		
96	8:26	9:32	1:06
112	8:36		
128	9:17	9:42	0:25
144	9:24		
160	9:38	9:52	0:14
176	9:47		
192	9:59	10:22	0:23
208	9:58		
224	10:03	10:38	0:35
240	10:09		
256	10:16	11:00	0:44
272	10:24		
288		11:15	
304			
320		11:22	
Total Trucks	17	10	
Total Feet delivered	272	320	

Table 12: Time Lag Between Lifts – Cell 72

Feet Delivered	Time of Arrival		Paving Lag	Feet Delivered	Time of Arrival		Paving Lag
	CHP	EAC			CHP	EAC	
16	8:13			368	11:56		
32	8:23	9:15	0:52	384	12:04	12:58	0:54
48	8:30			400	12:18		
64	8:45	9:57	1:12	416	12:37	13:34	0:57
80	8:55			432	12:48		
96	9:20	10:14	0:54	448	12:53	13:26	0:33
112	9:28			464	13:04		
128	9:33	10:36	1:03	480	13:09	13:38	0:29
144	9:45			496	13:17		
160	9:48	10:55	1:07	512	13:20	14:27	1:07
176	9:54			528	13:31		
192	9:58	11:12	1:14	544	13:35	14:51	1:16
208	10:03			560	13:41		
224	10:18	11:41	1:23	576	13:42	14:51	1:09
240	10:25			592	14:04		
256	10:39	11:49	1:10	608	14:13	15:03	0:50
272	10:45			624	14:32		
288	11:00	12:05	1:05	640	14:37	15:14	0:37
304	11:05			656	14:45		
320	11:20	12:16	0:56	672	14:56	15:25	0:29
336	11:29			688	15:18		
352	11:41	12:38	0:57			15:55	
				Total Trucks	22	11	
				Total Feet Delivered	352	352	

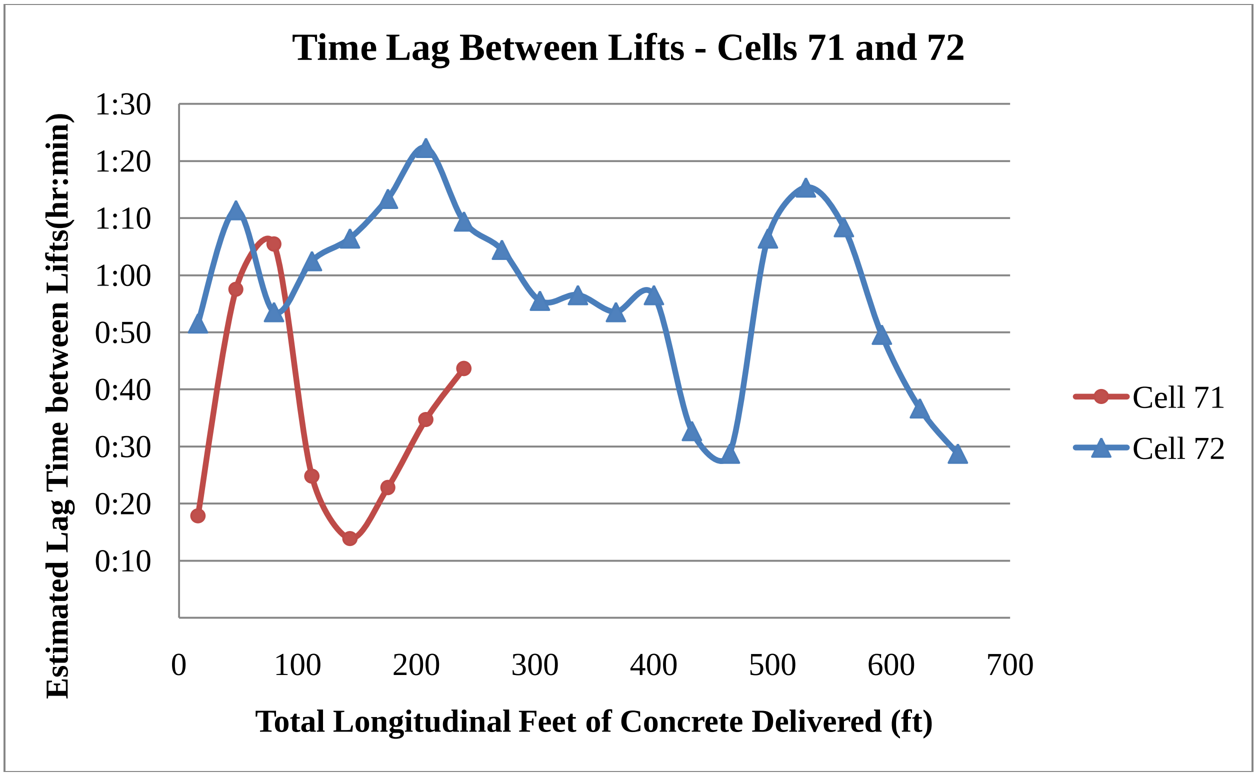

Figure 18: Time Lag Between Lifts – Cells 71 and 72

This plot clearly illustrates the differences in lag time between the two cells and within the cells themselves. Cell 72, however, does seem to generally have a much longer delay in paving between the two lifts than cell 71. This may be because construction of the top lift of cell 71 began much sooner after the bottom lift than in 72. However, paving of the top lift in cell 71 seemed to slow down as time went on, with the major drop in lag time due to two loads of lower lift concrete being rejected. The lag between lifts in 72 seems to be more erratic, with more frequent jumps and dips. The two plots below show progression of each lift separately to illustrate which layer was experiencing delays. A larger gap between the two lines corresponds to a longer lag between paving of the two lifts.

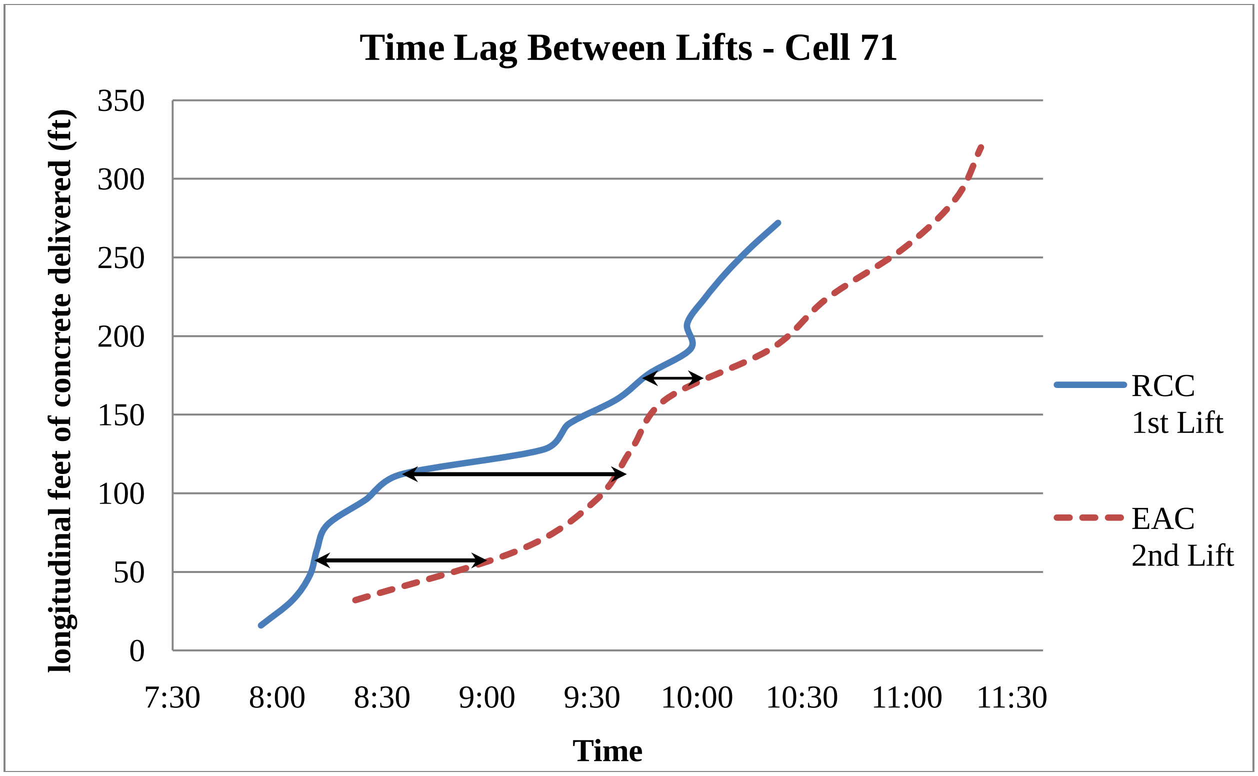

Figure 19: Time Lag Between Lifts – Cell 71

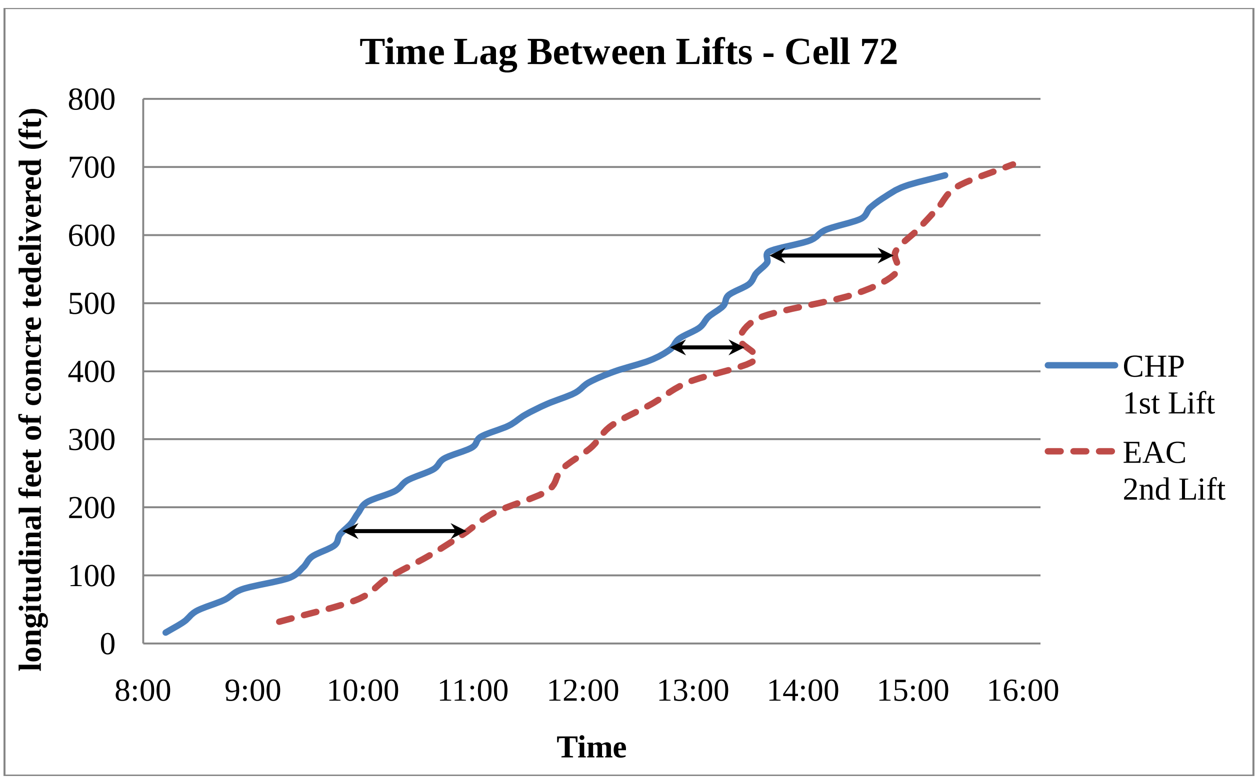

Figure 20: Time Lag Between Lifts – Cell 72

EARLY PERFORMANCE EVALUATION

The last chapter described the construction method of the three composite test cells at the MnROAD facility. This chapter will provide the test methods and results from the early performance assessment of the cell 70 (hot mix asphalt over recycled aggregate concrete), cell 71 (diamond ground concrete over recycled aggregate concrete) and cell 72 (exposed aggregate concrete over low cost concrete). Flexural, compressive and bond strength, along with noise and surface characteristics of the three cells will be discussed in this chapter. This includes on board sound intensity (OBSI), sound absorption, friction, and surface texture and the international roughness index.

Compressive, Flexural and Bond Strength

Compressive and flexural strength specimens were made at the construction site at the time of paving using the three different concrete mixes used in cells 70, 71 and 72. Composite beams with 2 different mix layers were made using different combinations of the three mixes. The specimens were transported back to the Mn/DOT Office of Materials and Road Research after initial curing. They were tested by the concrete laboratory staff using ASTM C39, standard test method for compressive strength of cylindrical concrete specimens, and ASTM 257, standard test method for flexural strength of concrete using a simple beam with third-point loading. The results are shown in the plots below.

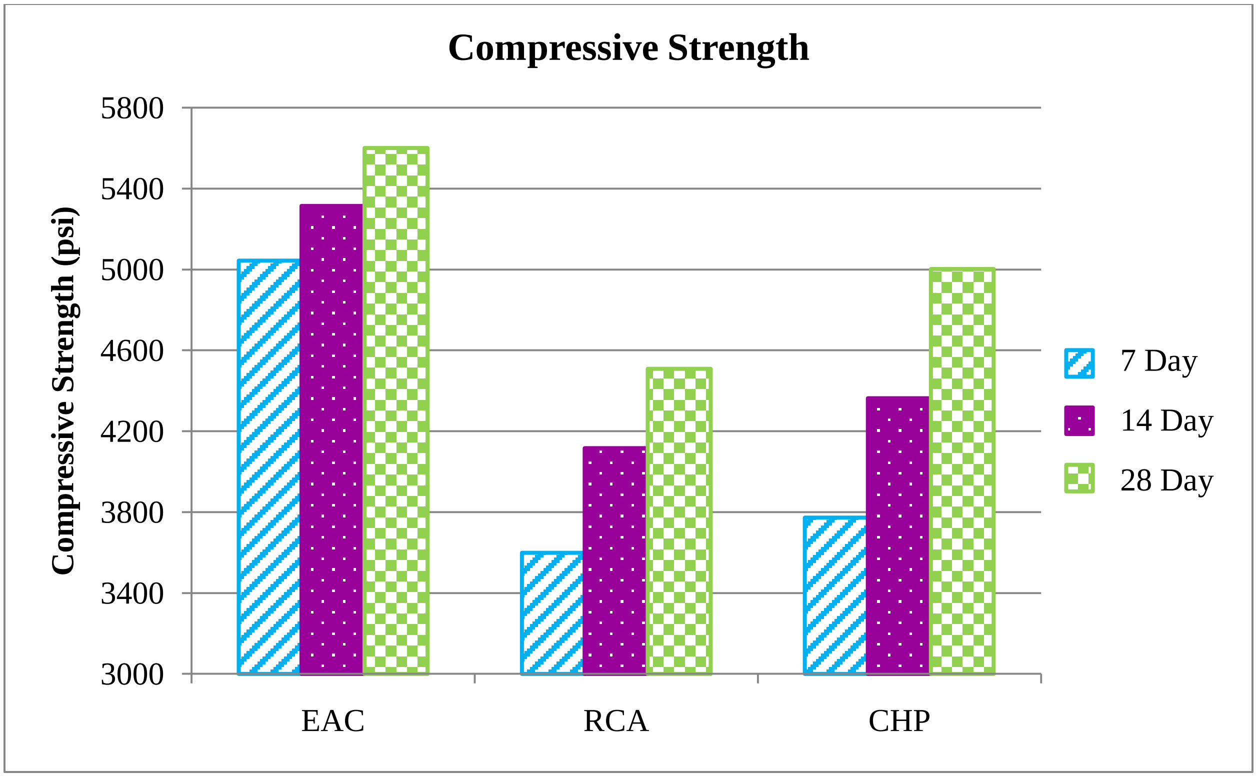

Figure 21: Compressive Strength

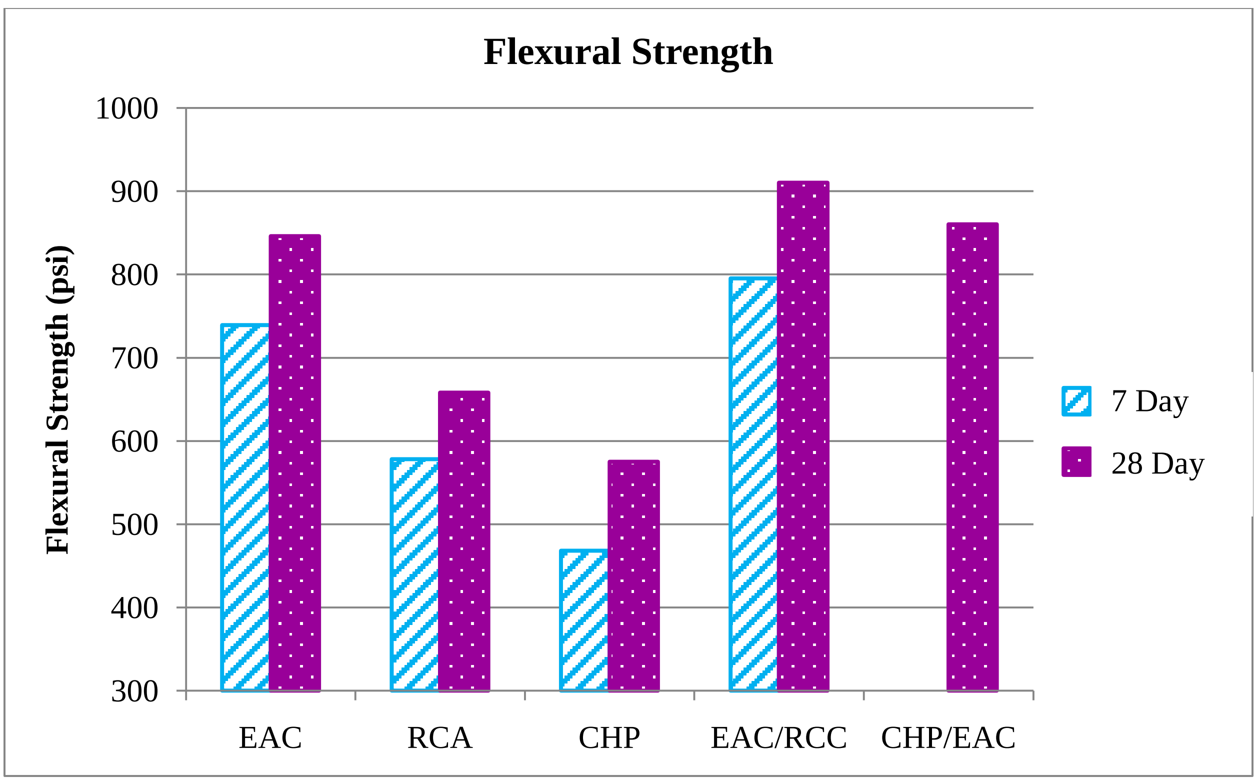

Figure 22: Flexural Strength

As expected, the exposed aggregate concrete achieved higher flexural and compressive strength than the low cost mix and the recycled mix. This difference in strength illustrates the change in quality between the two layers of the composites. Interestingly, however, the two composites (exposed aggregate concrete with both the low cost mix and the recycled mix) achieved slightly higher strength than the fully exposed aggregate concrete beams. When the composites were tested, they were placed in the third point bending machine such that the exposed aggregate concrete layer was in tension, and the lower quality (RCC or CHP) mix was in compression. Because of this load orientation, the measured flexural strength was essentially the strength of the exposed aggregate concrete. This explains why exposed aggregate beam and the composite beams achieved comparable flexural strengths. In the future, composite beams should be tested in a multitude of different orientations, with the bond plain both vertically and horizontally, to avoid this phenomenon.

The bond strength between the two layers of the composite pavements is another very important property that may influence long term performance. Due to the brittle nature of concrete, it is difficult to test bond strength by applying tension. Instead, slant-shear cylindrical specimens were made to test bond strength in accordance with ASTM C882, standard test method for bond strength of epoxy-resin systems used with concrete by slant shear. The specimens were made at the paving site by bonding two layers of concrete, EAC over CHP or EAC over RCC, at an angled plane in a cylinder. An example of a slant shear specimen is shown in figure 19. The two layered specimen is then tested in compression. Due to the specific angle of the bonded plane and the resulting stresses at the interface layer, the measured maximum applied compressive load is the bond strength between the two layers. The following plot shows the measured bond strengths of EAC over RCC from cell 71 and EAC over CHP from cell 72. Specimens were also made and tested using the concrete from the demo slab.

Figure 23: Slant Shear Specimen

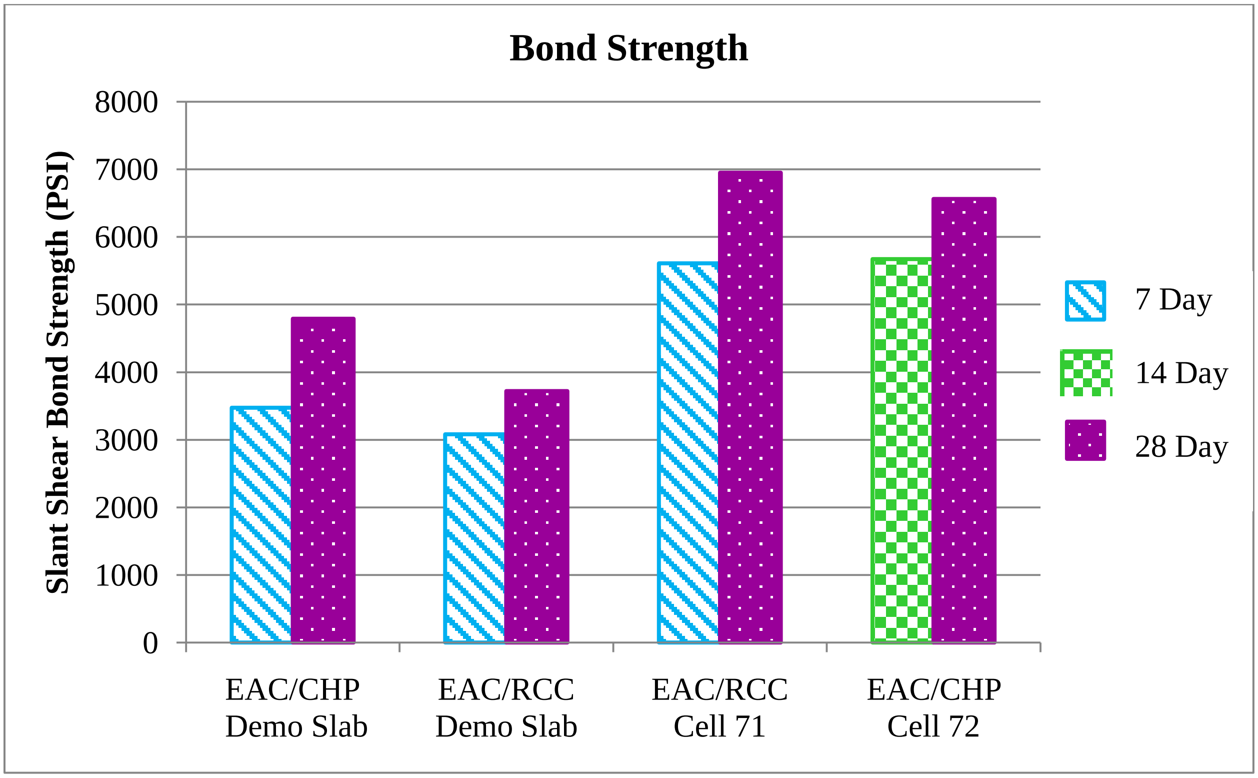

Figure 24: Bond Strength

All of the specimens tested achieved a bond strength well over 1000 psi, the minimum to be considered adequate a bond between concrete in pavement applications. It is interesting to note the reduced bond strength in the specimens made from the demo slab concrete. Also, the bond between EAC and CHP seems to be stronger than the EAC and RCC in the demo slab concrete, however the opposite trend was observed in the specimens made from cells 71 and 72.

On Board Sound Intensity

The On Board Sound Intensity (OBSI) test measures the noise generated from the tire – pavement interaction. Mn/DOT became one of only five states to utilize OBSI when it began testing in 2007. One advantage of using the OBSI method to measure sound generation making it favored to the traditional Statistical Pass By Method is that it allows the noise generated from the pavement-tire interaction to be isolated from other sources, such as engine noise and the surrounding landscape noise. OBSI testing is done according to the AASHTO TP 79-08 (11) procedure. The process analyzes data recorded with microphones located close to the tire-pavement contact. The dominant noise generation source becomes the tire-pavement interaction when cars travel at freeway speeds. Therefore, the test is performed at 60 mph over a 440 foot stretch of pavement to adequately capture the desired noise source.

The OBSI test set-up consists of a sedan outfitted with four GRAS sound intensity meters, a BRUEL AND KJAER front-end four-channel frequency analyzer and a standard reference test tire (SRTT). The microphones are suspended from the vehicle frame and positioned at 3 inches vertical displacement and 2 inches lateral displacement from the leading and trailing end of the standard reference tire and pavement contact. The microphones are anchored to a free rotating ring mounted on the right wheel that allows the microphone assembly to be fixed in position and direction without inhibiting the rotation of the tire.

Figure 25: OBSI Device

PULSE noise-and-vibration software installed in a connected computer. The computer receives and analyzes the data categorizing the response into component third octave frequency output. Pavement noise response from the microphones is condensed into a third octave frequency sound intensity plot averaged for the leading edge and trailing edge. The OBSI parameter is the average of the logarithmic sum of the sound intensity at 12 frequencies **(**400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, and 5000 Hz). OBSI analysis is based off the AASHTO TP76-08 protocol. It is computed for the two microphones using the following equation, where SI_i (i= 1,2,3…12) are sound intensities in dBA at each of the 12 third octave frequencies.

The implication of an OBSI difference in terms of actual percentage reduction in sound level deserves explanation. A 3-dBA reduction is tantamount to approximately 50 percent loss of sound intensity from a uniform source. If , and the respective sound intensities are and in Watts /m^2 respectively, then – – equals *n*, where I_0 is the sound intensity at the threshold of human hearing. Therefore, – –. For instance, when the difference in OBSI is equal to 3 dBA, the ratio of actual sound intensity is 2.

When the difference in OBSI is equal to 6 dBA, the ratio of sound intensity is 4. The results from OBSI testing done in 2010 are shown in the plots below.

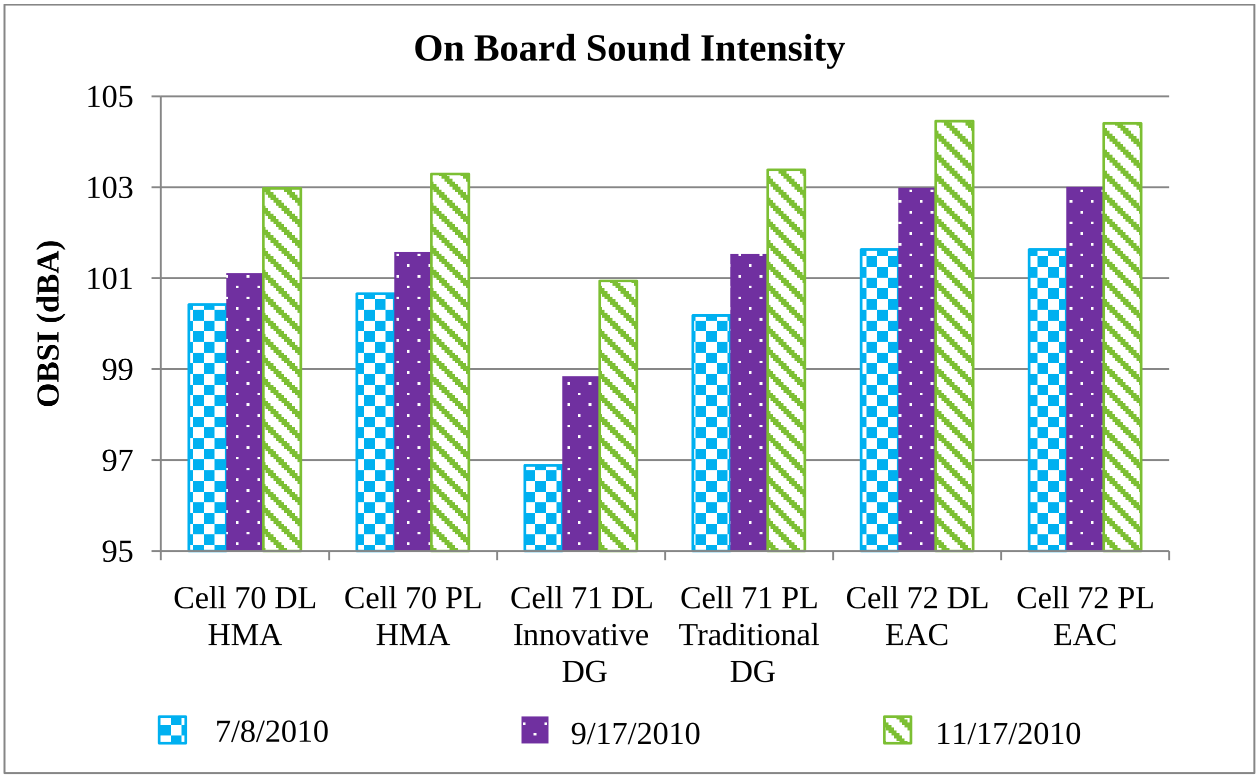

Figure 26: OBSI – All lanes

This chart shows that the innovative diamond ground exposed aggregate concrete in cell 71 has the lowest OBSI throughout the three months tested. The traditional diamond grind has similar OBSI to the hot mix asphalt. More significantly, the exposed aggregate finish consistently has the highest OBSI. There is not a considerable difference between the OBSI in the passing lane versus the inside lane in either cells 70 or 71. Pavements are usually considered quiet when they achieve an OBSI less than 100 dBa, in which case the data suggests that the diamond grind in cell 71 is the only composite pavement to be considered quiet. In a survey of exposed aggregate concrete pavements in Europe conducted by the National Concrete Pavement Technology Center, OBSI values were found to range from 101 to 106 dBa, which is similar to the results obtained for cell 72 [5]. The 1/3 octave sound intensity spectrums used to calculate the OBSI values above are show in the following three figures. All cells show similar shape in their sound intensity spectrums.

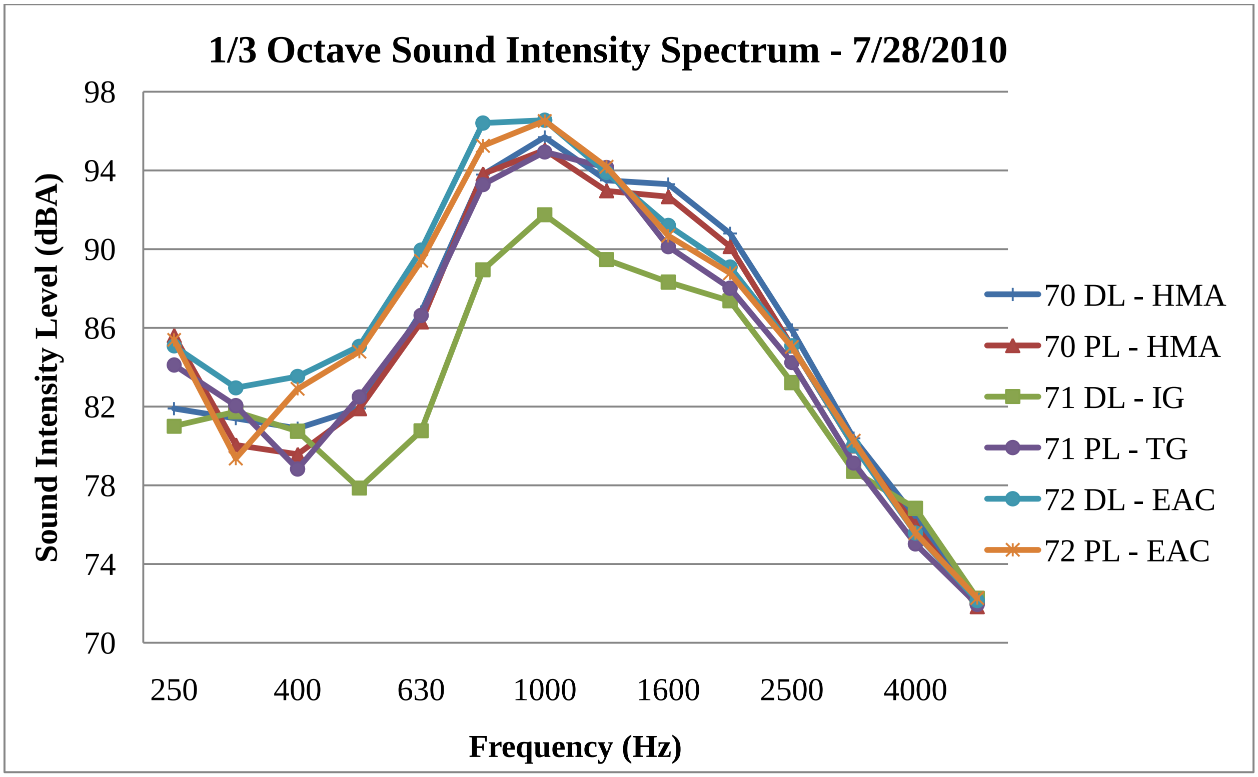

Figure 27: Sound Intensity Spectrum – 7/28/2010

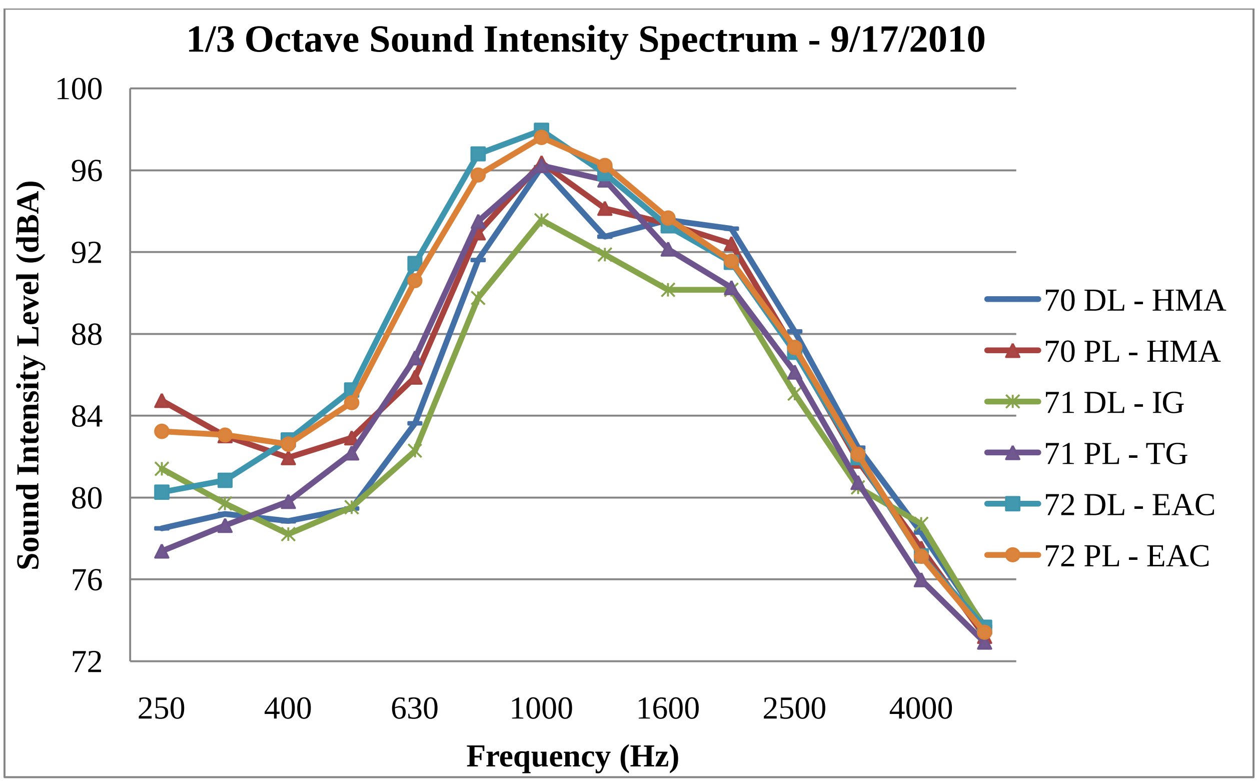

Figure 28: Sound Intensity Spectrum – 9/17/2010

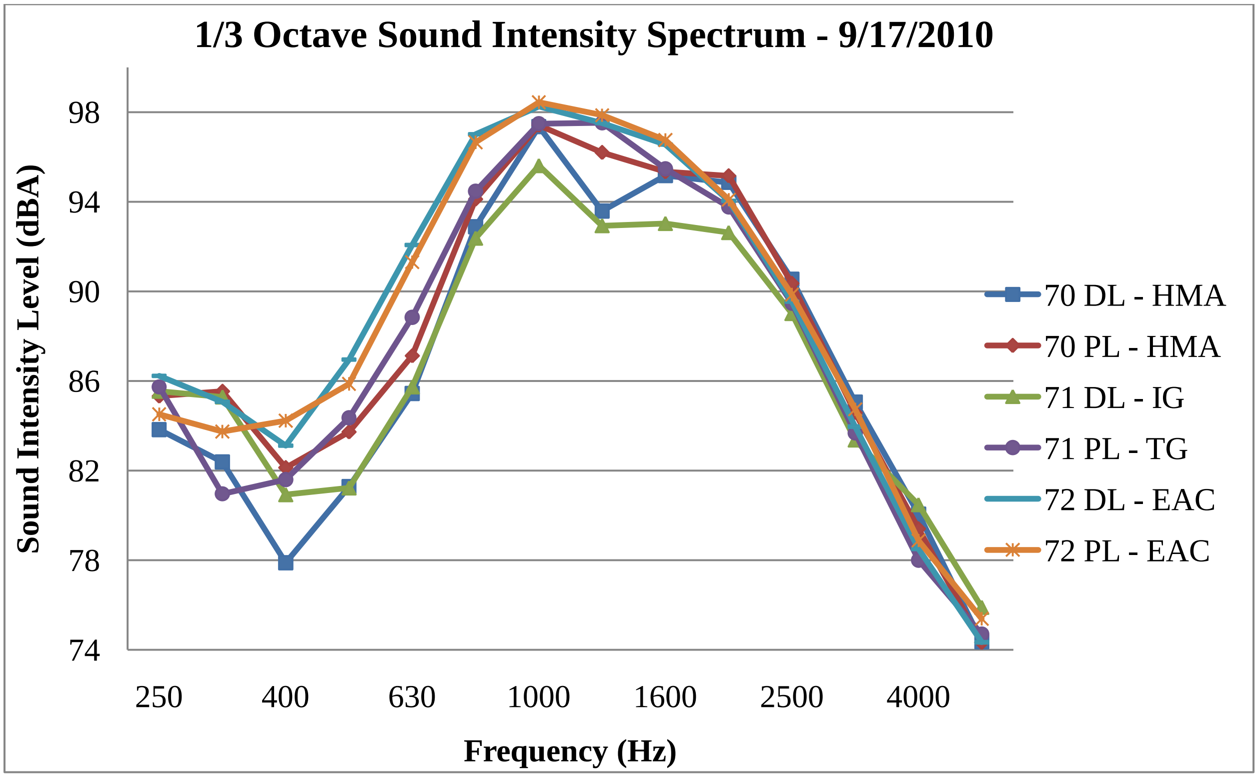

Figure 29: Sound Intensity Spectrum – 9/17/2010

Sound Absorption

The Sound Absorption Coefficient is the ratio of the absorbed sound energy to the transmitted sound energy of the pavement surface. The ratio is measured when a white noise of frequency ranging from 315 to 1800 Hz is projected into the pavement within an impedance tube placed normal to the pavement surface. The setup for measuring Sound Absorption using a BSWA 425 device is shown in figure 30.

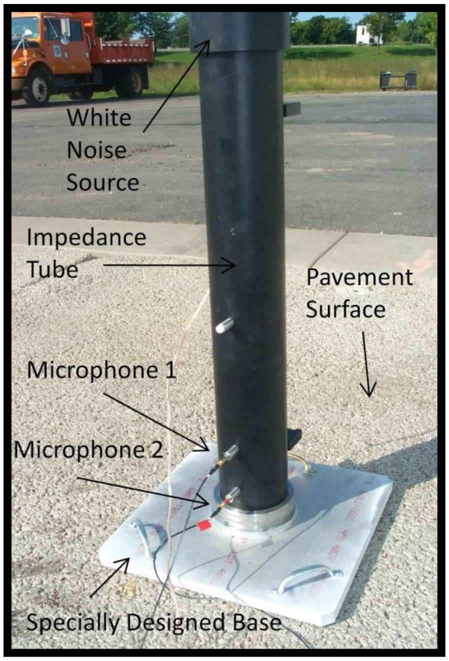

Figure 30: Sound Absorption Impedance Tube

During the test sound absorption test, the sound analyzed is generated by a white noise source above the impedance tube. White noise is a random audio signal with a flat power spectral density that contains noise at the same power at all frequencies. During the test, the impedance tube is placed on the pavement surface and a set of sensitive microphones are attached to the pre-installed housing at the lower end of the tube. These microphones are also connected to an analyzer. The noise source sends the incident sound energy (white noise) to the surface and the incident and reflected waves are captured by the two microphones. Software then windows the reflected waves and converts the data to the 3rd octave sound absorption coefficient at 315, 400, 500, 750, 1000, 1250 and 1650 Hertz. A range of frequencies of the n-th octave are determined by the following equation.

Sound absorption coefficients range between one and zero, where a value of one would mean that all of the sound is being absorbed.

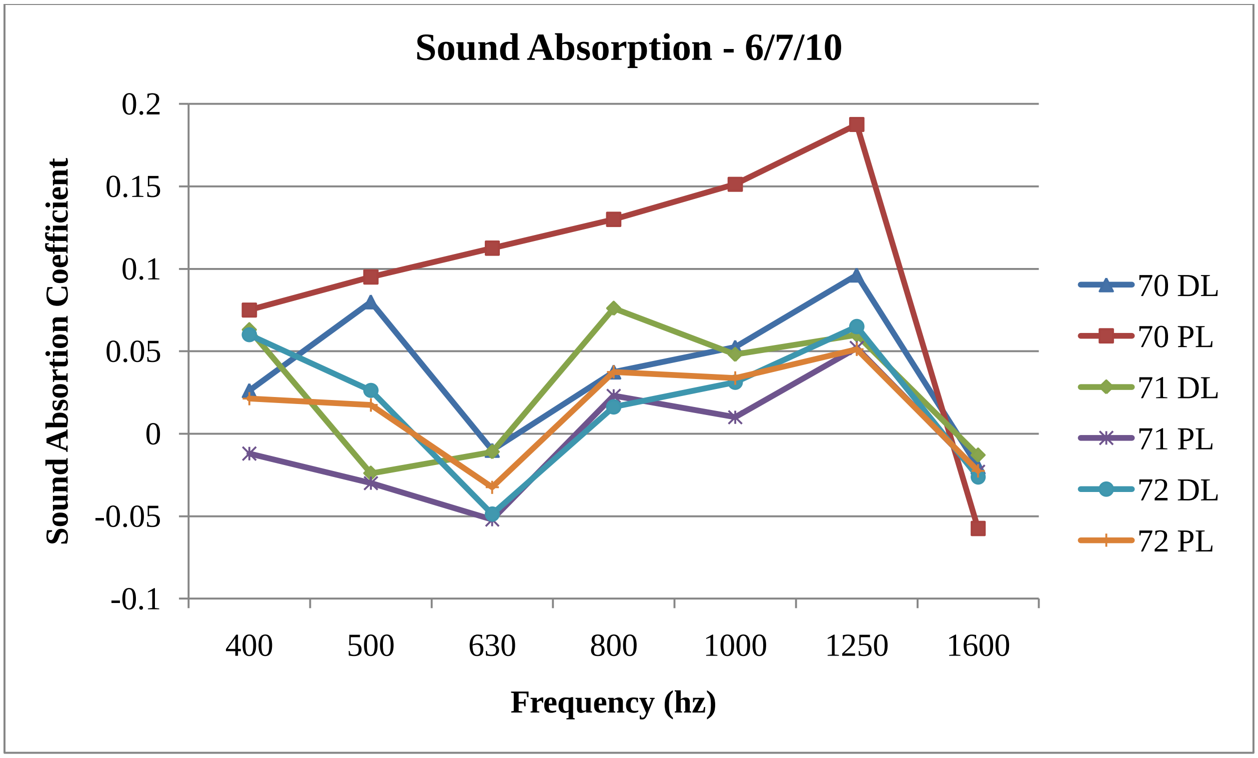

Figure 31: SA Coefficient Spectrum – 6/7/10

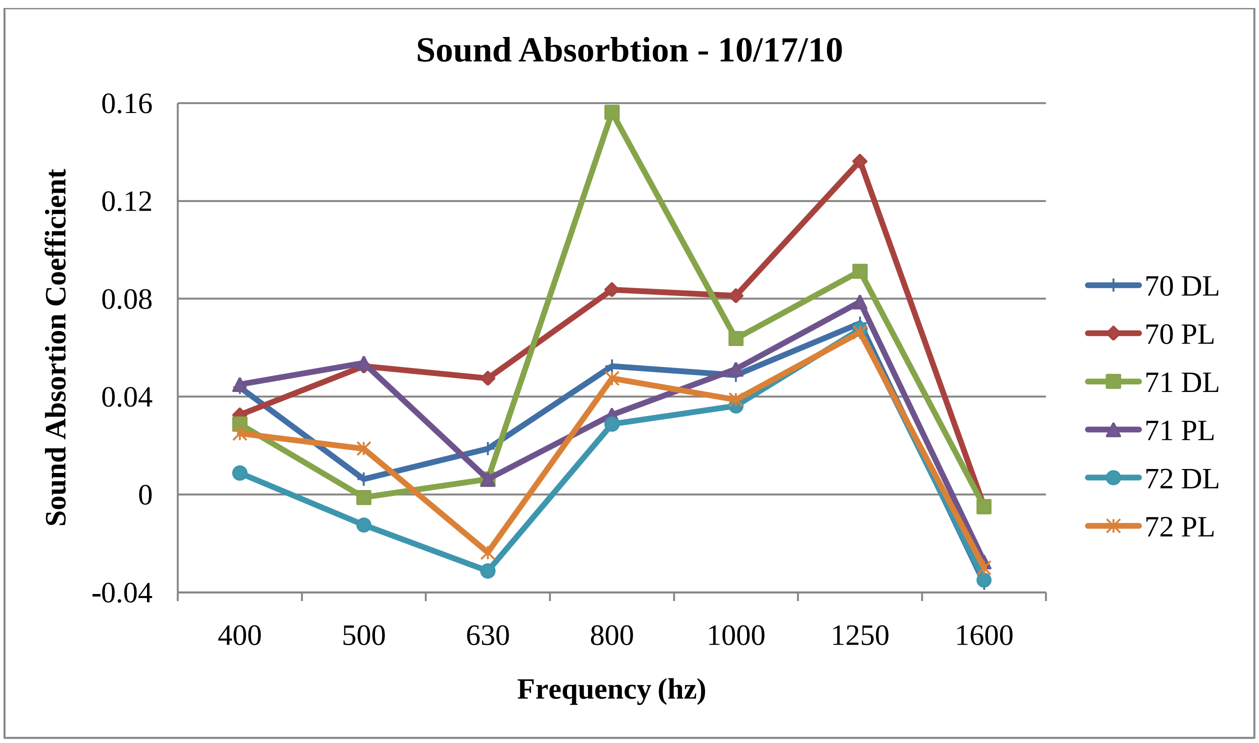

Figure 32: SA Coefficient Spectrum – 10/17/10

The negative sound absorption coefficients in the plots above imply that more sound is being measured by the microphones than is being emitted from the noise source. This suggests that there was “contamination” during testing and the tube-base combination did not adequately block sound from outside noise sources. For a more useful comparison between the sound absorption in different cells, the absorption coefficients at 1,000 hz are given in the chart below. The 1,000 hz frequency is chosen because it is commonly considered the frequency at which the tire-pavement interaction noise is the highest [6].

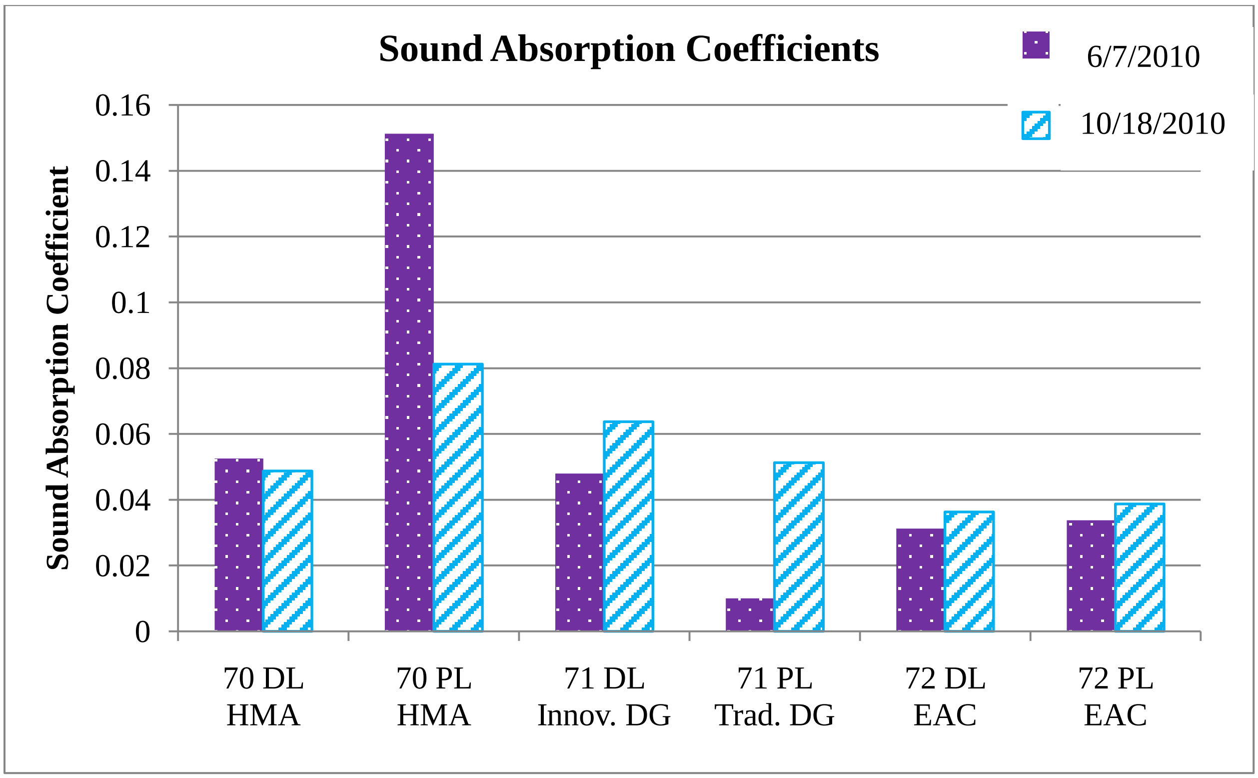

Figure 33: Average SA at 1000 hz – All Cells

The hot mix asphalt shows the highest sound absorption of all the composite cells. The diamond grind in cell 71 generally has higher absorption than the exposed aggregate in cell 72. As expected, the innovative diamond grind has higher sound absorption than the traditional diamond grind.

Friction

The standard method for testing friction at MnROAD utilizes the KJ Law Friction Trailer to perform skid testing of the pavement surface. Friction testing is done in accordance with the following three ASTM standards: ASTM E274 standard test method for skid resistance of paved surfaces, ASTM E501 skid testing using a standard ribbed tire, and ASTM E524 skid testing using a smooth tire. Both ribbed and smooth tires are used because they each measure adhesion and hysteresis differently. Since the ribbed tire removes the water from the surface more efficiently than the smooth tire, it generally examines the pavement friction on the micro-texture portion. The smooth tire, however, is more affected by the macro-texture. If the macro-texture doesn't adequately drain water on the pavement surface, the smooth tire will hydroplane and result in lower friction values. The locked-wheel skid trailer and truck setup is shown in the figure below.

Figure 34: KJ Law Friction Trailer and Truck

The vehicle carries a supply of water that is sprayed directly in front of the test tire to test the pavement when it is wet. The trailer is towed behind a vehicle at a speed of 40 miles per hour to measure the coefficient of friction. When the skid trailer reaches the testing area, a measured amount of water is applied to the pavement in front of the test tire. Then the tire, ribbed or smooth, locks in place and the wheel is pulled along for a specified length. This setup applies both vertical load forces and horizontal drag forces to the pavement. The device measures the amount of tractive force required to pull the trailer. The measured force is then sent to a laptop, which is stored inside the tow vehicle. Finally, the friction number is calculated by the ratio of tractive force to the known wheel load multiplied by 100.

The test is performed on both wheel paths. The average of the measurements from each wheel path is used to calculate the friction number for the lane. The test generates friction numbers ranging from 0 to 100, with higher numbers indicating higher friction. A pavement with a friction number of 25 f from a smooth tire is considered a safe pavement with adequate skid resistance, while a pavement with a friction number less than 15 would require rehabilitation to achieve sufficient skid resistance [8]. The measured friction numbers from cells 70, 71 and 72 using both a ribbed and smooth tire are shown below.

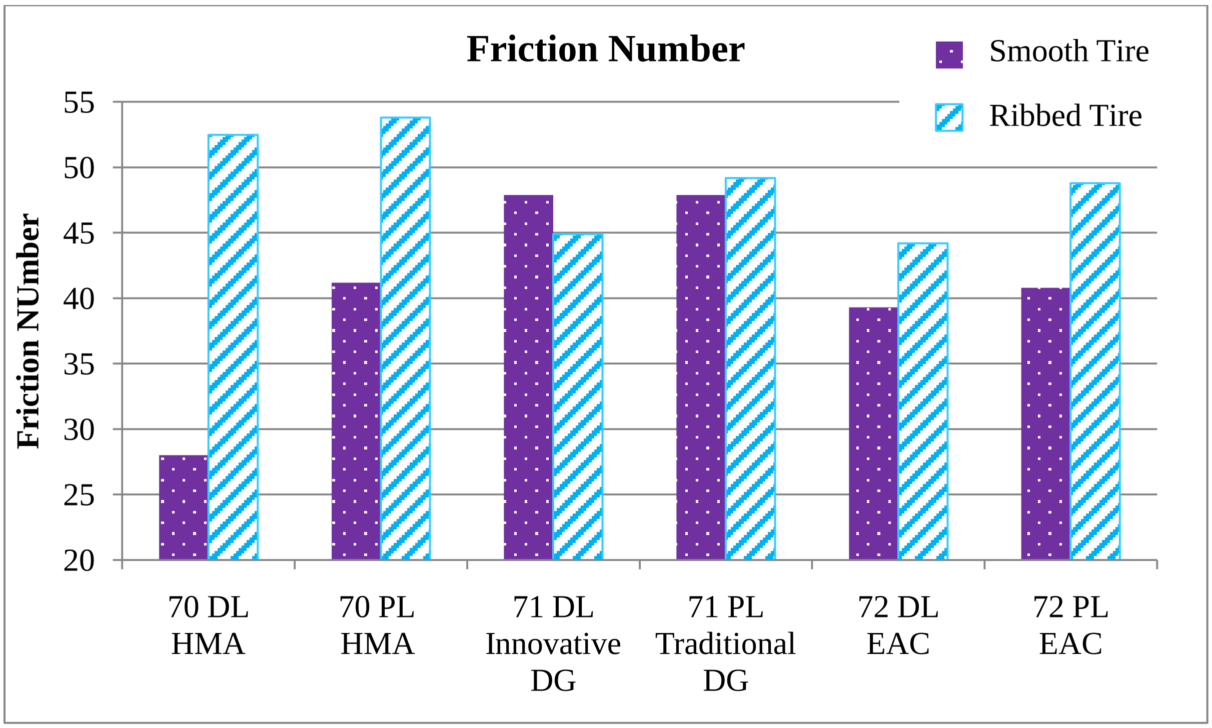

Figure 35: Friction Number

This plot shows that all three test cells achieved adequate skid resistance for driver safety. The hot mix asphalt in cell 70 achieved the highest friction number when testing with the ribbed tire, but achieved the lowest friction number with testing with the smooth tire. The diamond grind in cell 71 consistently achieved better friction that the exposed aggregate in cell 72. However, this difference is only significant in tests done with the smooth tire. When testing with the ribbed tire, the diamond grind and exposed aggregate achieved comparable results.

Texture

The circular track meter (CTM) shown in figure 30 below is a laser-equipped device that scans the surface of a pavement in accordance with ASTM E2157. The CTM is equipped with a charged coupled device (CCD) laser displacement sensor that sweeps the pavement surface in a circle 11.2 inches in diameter and 35 inches in circumference. The displacement sensor for this instrument is mounted on an arm that rotates at 3 inches (80-mm) above the surface. The arm moves at a tangential velocity of 6 m/min. Using this mounting, the CCD displacement is sampled 1,024 times per revolution, providing a sample spacing of 0.87 mm. The data is segmented into eight 111.5 mm arcs of 128 samples each. From each segment, the computer software computes the mean profile depth (MPD), the root-mean-square texture depth (RMS) of each segment, and the average of all eight-segments. A plot of the 8 segments of MPD is also produced. This plot is difficult to decipher unless the sweeping action of the laser in each sector is visualized. Effectively, only 2 of the 8 segments mimic the texture. The mean profile depth generated from the CTM on two different occasions is shown in the plot below.

Figure 36: Circular Track Meter

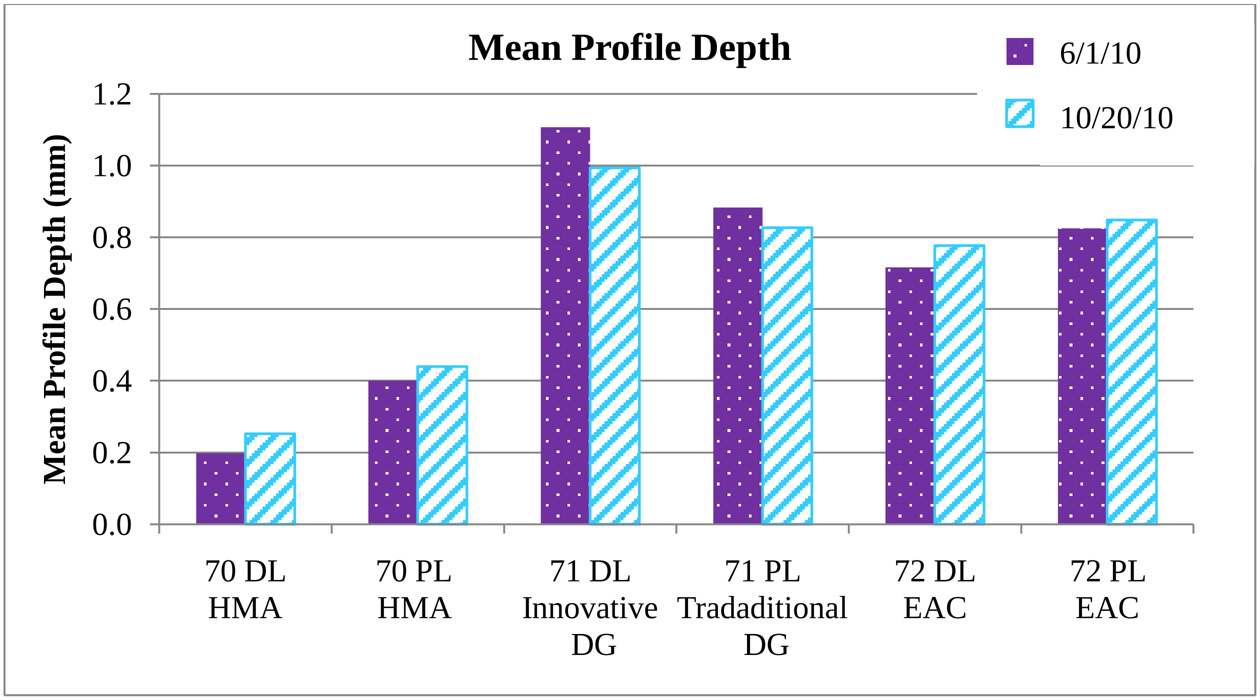

Figure 37: Mean Profile Depth

The diamond grind in cell 71 and the exposed aggregate in cell 72 have significantly higher mean profile depth (MPD) than the HMA in cell 70. There is a consistent increase in MPD from the driving lane to the passing lane for cells 70 and 72, which suggests traffic loading can influence pavement texture. The innovative diamond grind in cell 71 was consistently higher than both the traditional grind and the exposed aggregate concrete. There was no trend in the change in MPD from summer to winter months.

International Roughness Index

The international roughness index is the universally accepted standard measure of ride quality and pavement smoothness. Various vehicles respond to various surface profiles according to their natural frequencies, their sprung masses, spring constants and dashpot constants. IRI is based on the vertical response of the suspension of a quarter car normalized to a speed of 50 miles per hour riding over the pavement surface. This measurement is only as good as the degree to which the equipment or ride algorithm responds to the preponderant frequencies in the pavement surface. The response multiplier algorithm in figure 38 is expected to mimic human response to the corresponding frequencies. The IRI multiplier algorithm is not uniform in all wavelengths but the gain algorithm peaks at the quarter car resonant frequencies as well as what are assumed to be the body excitation frequencies. Wavelengths that are considered significant based on ride comfort receive higher gain in the IRI algorithm.

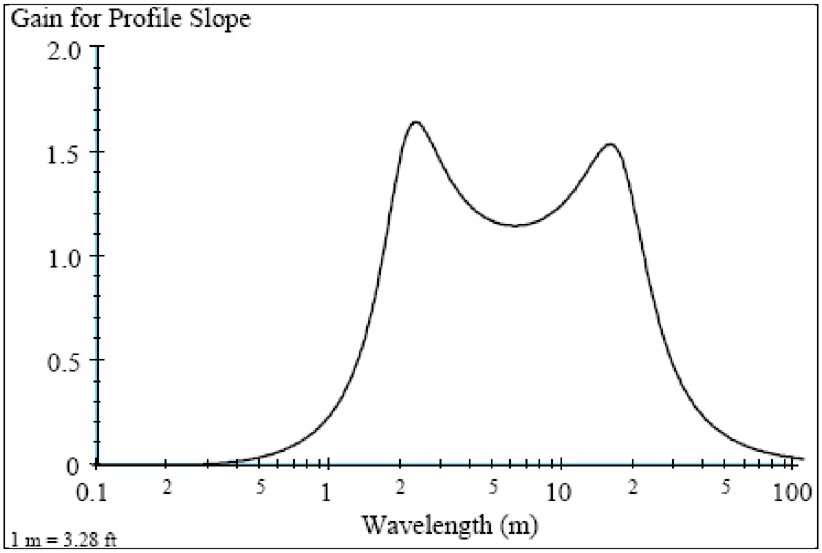

Figure 38: IRI Multiplier Algorithm

The International Roughness Index is designed to be more sensitive to certain frequencies than others in order to represent how the rider feels. In addition to the amplified response of the quarter car to certain frequencies, errors resulting from any deviation from the smooth profile are only predictable to the degree of response of the quarter car algorithm to that profile.

The International Roughness index has been variously defined from the simple description of what the name implies (a roughness Index) to the definition in the frequency domain. One definition of IRI is the average rectified value of the Slope Power Spectrum Density of the profilogram. In other words, IRI is a mathematical property of a two-dimensional road profile, a slice of the road showing elevation as it varies with longitudinal distance along a travelled track on the road. As such, it can be calculated from profiles obtained with any valid measurement method, ranging from static rod and level surveying equipment to high-speed inertial profiling systems.

The international roughness index (IRI) is a roughness indication calculated from the longitudinal profile and is reported in units of in/mi. It is the sum of the deviations from an assumed plane surface based on the vertical acceleration of the quarter car in response to the surface profile. The IRI algorithm is therefore subject to the resonant frequency of the quarter car and provides different multipliers for different frequencies to mimic the human comfort level. In consequence, certain dominant frequencies have much more effects than others in tactile and in sonic spectra.

The unit for IRI, meters per kilometer or inches per mile, superficially indicates unevenness of the test length per unit length. The profilogram is not a true spatial profile but an indication of how the quarter car rides on the surface. Wavelengths that are considered significant based on ride comfort receive higher gain in the IRI algorithm. IRI is summarily a measure of pavement smoothness or ride quality based on the response of the quarter car. This single number is also viewed as the accumulation of the vertical displacement of a standard car per unit horizontal distance travelled with reference to an assumed neutral plane.

Mn/DOT measures IRI with a Lightweight Inertial Surface Analyzer (LISA) shown in figure 39. The LISA is a profile device that measures the amount of vertical rise over a horizontal distance. This is done with two separate laser sources on the side of the vehicle. One laser takes continuous profile measurements over a four inch path while the other measures three discrete profiles across the four inch path. The raw data is then used to calculate the IRI, with higher IRI corresponding to rougher pavement.

Figure 39: Lightweight Inertial Surface Analyzer

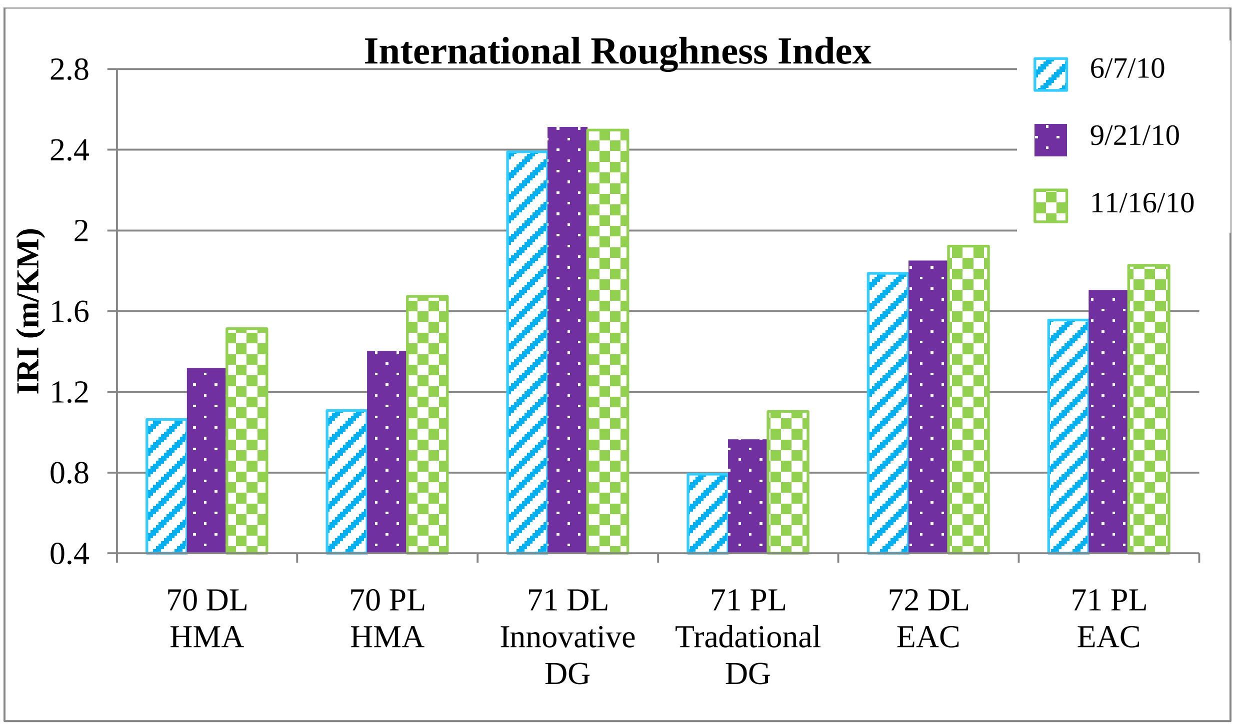

Figure 40: International Roughness Index

The FHWA roughness categories place pavements with IRI values less than 1.5 as in "good" condition, while pavements with an IRI more than 2.6 are considered "unacceptable". By this standard, all test cells achieved acceptable IRI, but only the hot mix asphalt and traditional grind concrete were categorized as “good” pavement. More significantly, the exposed aggregate has higher IRI values than all surfaces except for the innovative diamond grind.

‘Warp and Curl’

Mn/DOT recently developed the second Automated Laser Profile System (Alps 2) to analyze ‘warp and curl’ that pavements experience. Pavement warping and curling refers to the bending stresses caused by temperature and moisture differentials throughout the pavement depth. For example, during evening hours when the ambient temperature drops, the top portion of the pavement cools quickly while the bottom remains heated. This causes the pavement to curl upwards while the weight of the slab acts as the restraint producing bending stresses. A similar effect can occur in the afternoon, when high ambient temperatures heat the pavement surface while the lower pavement stays cool. Some believe that composite pavements may have the ability to mitigate warping and curling. However, relatively little work has been completed to fully understand composite pavements’ reaction to the driving environmental forces and the impact on long term performance. Monitoring the composite cells using the Alps 2 equipment was done to better understand this behavior. Testing began immediately after construction, with trust runs completed twice a day. To obtain profile measurements when the most extreme warp and curl is expected, test runs were conducted at 3 am and 3 pm, during the average daily minimum and maximum temperatures respectively.

The MnROAD developed Alps 2 device shown in figure 41 collets automated measurements of the pavement profile. The device consists of a 15 foot laser mounted to a vehicle that travels down the roadway. The profile measurements are taken at one inch intervals in both the longitudinal and transverse directions. All of the data collected from the profiler for a particular test is then saved in an EXCEL comma-delimited file which contains thousands of lines of data from various runs, tests cells, and panels. The file is run through a macro which sorts the data based on the run number, panel, and test cell. The data is then graphed to allow the user to easily understand the measurements. An example of the resulting profile graph from a typical pavement is given in figure 42 below. This three dimensional figure demonstrates how clearly the physical warp and curl of the pavement surface can be detected.

Figure 41: (a) and (b) Alps 2 Equipment

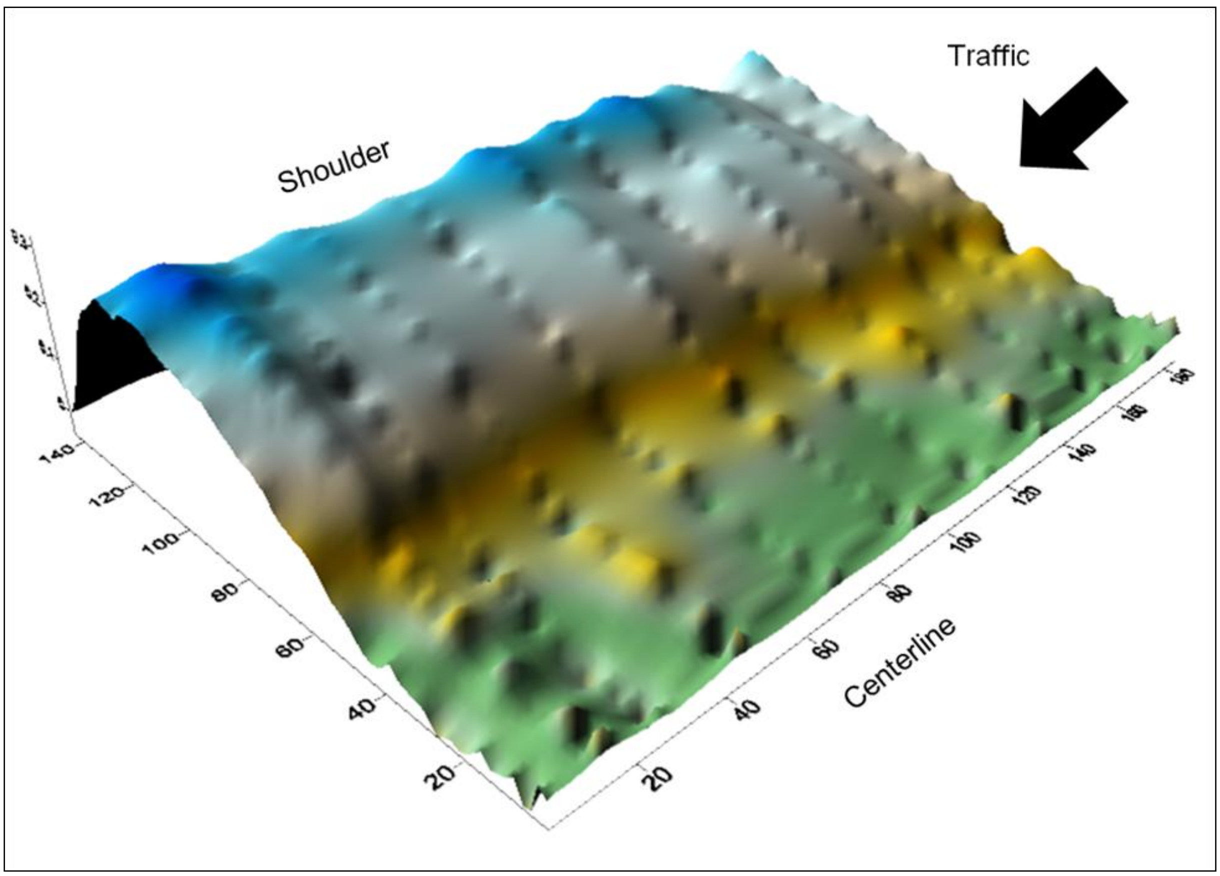

Figure 42: Alps 2 Profile Example

The profile measurements collected from ‘warp and curl’ monitoring of cells 70, 71 and 72 using the Alps 2 device will be very useful in understanding composite pavement behavior to environmental factors. This data, along with recent measurements of OBSI, sound absorption, friction, texture and IRI from further monitoring will be included in future performance reports.

CONCLUSION

This paper summarizes the construction and early performance assessment of three composite test cells at the MnROAD: Cell 70, HMA over a recycled aggregate concrete; Cell 71, diamond grind concrete over recycled aggregate concrete; and Cell 72, exposed aggregate concrete over a low cost concrete. The construction of cells 70, 71 and 72 was part of R21 Composite Pavement project of second Strategic Highway Research Program. The following conclusions were made on the different composites and surfaces tested:

- Early performance assessment of the three test cells suggest that the exposed aggregate concrete surface does not provide significant noise reduction, as it had higher OBSI than both the HMA and traditional diamond grind surfaces tested.
- Innovative diamond grinding of composite pavements may be beneficial for noise reduction, as it showed lower OBSI than the HMA, EAC, traditional grind surfaces, and also had greater sound absorption than EAC.
- Exposed aggregate surfacing can provide more than adequate friction for driver safety, but does not show any improvement from typical HMA or diamond ground surfaces.
- Exposed aggregate surfaces have a similar texture (or mean profile depth) to traditional diamond ground surfaces. However, EAC may have reduced ride quality as IRI values were higher than both HMA and traditional diamond grind surfaces.

Although composite pavement systems have become extremely popular in Europe, they are still a relatively new concept to the United States, creating a demand for more research and performance data. Continued monitoring of these test cells will help develop the wide understanding of composite pavement performance needed for more effective design and accurate service life models.

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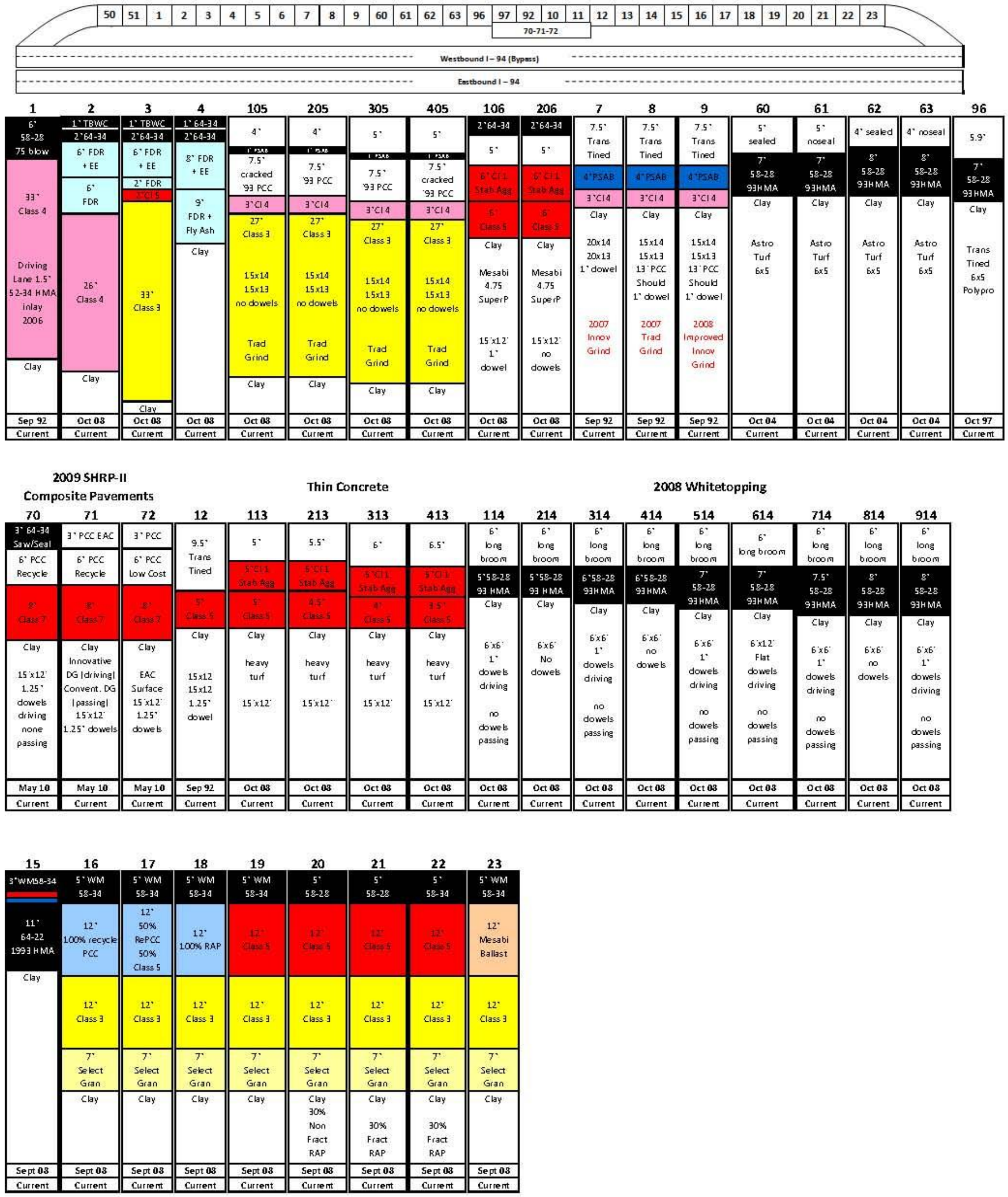
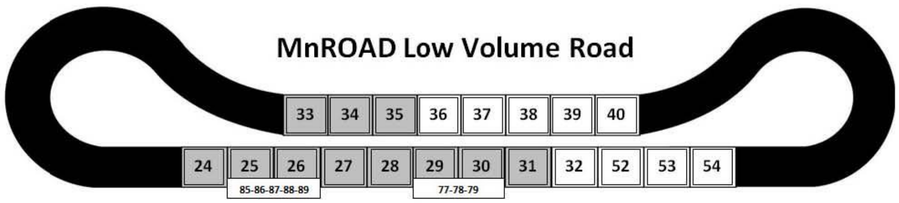
APPENDIX A

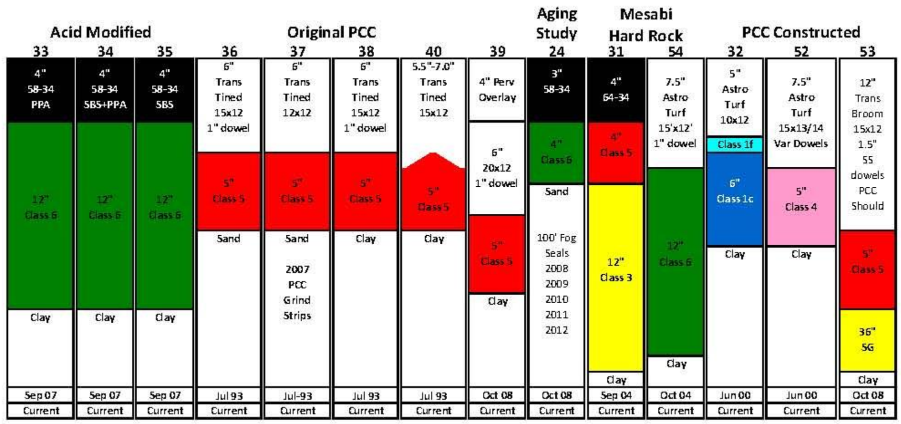
MnROAD Mainline and Low Volume Road Layout and Descriptions

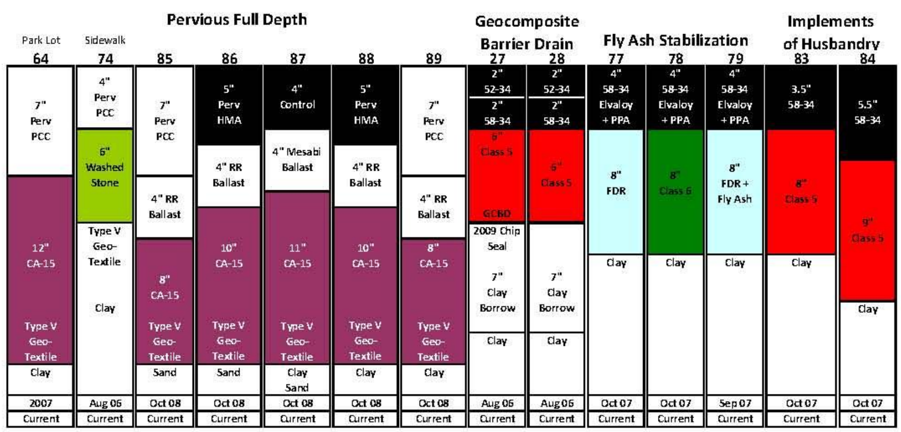
MnROAD Mainline



* All thicknesses shown as design thickness







* All thicknesses shown as design thickness

APPENDIX B

Mix Approval Requests and

Job Mix Formulas

REQUEST FOR CONCRETE MIX APPROVAL

Requested by	Tom Schmit	Phone	651-319-2369
Firm Name	Aggregate Industries		
Agency Enginner/Inspector		S.P.	8680-159

Proposed Aggregate Sources

	CA #1		CA #2		CA #3	Sand	
Pit Number	71041		71041			71041	
Pit Name	Agg. Ind.		Agg. Ind.			Agg. Ind.	
Nearest Town	Elk River		Elk River			Elk River	
Size	#4 (1-1/2")		#67 (3/4"-)			C. Sand	
Sp. G. & Abs. (Provided by MN/DOT)	2.75	0.90%	2.69	1.30%		2.63	0.90%

Proposed Cementitious Sources

	Cement	Fly Ash	Other
Manufacturer/Distributor	Holcim	Headwaters	
Mill/Power Plant	STGBLMO	COCUNND	
Type/Class	I/II	C/F	
Specific Gravity	3.15	2.5	

Proposed Mix Designs

MN/DOT Mix Number	CHPMR60		
Water (lbs/C.Y.)	173		
Cement (lbs/C.Y.)	240		
Flyash (lbs/C.Y.)	360		
Other Cementitious (lbs/C.Y.)			
W/CM Ratio	0.29		
Sand (Oven Dry, lbs/C.Y.)	1263		
CA #1 (Oven Dry, lbs/C.Y.)	787		
CA #2 (Oven Dry, lbs/C.Y.)	1102		
CA #3 (Oven Dry, lbs/C.Y.)	0		
Maximum Slump	3" Max		
% Air Content	7.00%		
Admix. # 1 (oz/100 # CM)	2.0 - 15.0 oz/cuyd Multi-Air 25		
Admix. # 2 (oz/100 # CM)	1.0 - 5.0 oz/cwt Sika 686		
Admix. # 3 (oz/100 # CM)	0.0 to 30 oz/cwt Sikaset NC (non-chloride accelerator)		

The above mixes are approved for use, contingent upon satisfactoiry site perfromance and continuous acceptability of all materials sources, by:

Maria Masten — 4/1/2010

Concrete Engineering ~~Specialist~~ — Date

Comments: attached composite gradation JMF 10-001 shall comply with the gradation requirements in the supplemental agreement No.1 Table 3137-4(a) + 3137-4(b).

REQUEST FOR CONCRETE MIX APPROVAL

Requested by	Tom Schmit	Phone	651-319-2369
Firm Name	Aggregate Industries		
Agency Enginner/Inspector		S.P.	8680-159

Proposed Aggregate Sources

	CA #1	CA #2	CA #3	Sand
Pit Number	71041	27005		71041
Pit Name	Agg. Ind.	McCrossan		Agg. Ind.
Nearest Town	Elk River	Maple Grove		Elk River
Size	#4 (1-1/2")	Recycle		C. Sand
Sp. G. & Abs. (Provided by MN/DOT)	2.75 0.90%	2.49 2.93%		2.63 0.90%

Proposed Cementitious Sources

	Cement	Fly Ash	Other
Manufacturer/Distributor	Holcim	Headwaters	
Mill/Power Plant	STGBLMO	COCUNND	
Type/Class	I/II	C/F	
Specific Gravity	3.15	2.5	

Proposed Mix Designs

MN/DOT Mix Number	RCCMR		
Water (lbs/C.Y.)	234		
Cement (lbs/C.Y.)	360		
Flyash (lbs/C.Y.)	240		
Other Cementitious (lbs/C.Y.)			
W/CM Ratio	0.39		
Sand (Oven Dry, lbs/C.Y.)	1200		
CA #1 (Oven Dry, lbs/C.Y.)	825		
CA #2 (Oven Dry, lbs/C.Y.)	920		
CA #3 (Oven Dry, lbs/C.Y.)	0		
Maximum Slump	3" Max		
% Air Content	7.00%		
Admix. # 1 (oz/100 # CM)	2.0 - 15.0 oz/cuyd Multi-Air 25		
Admix. # 2 (oz/100 # CM)	1.0 - 7.0 oz/cwt Sika 686		
Admix. # 3 (oz/100 # CM)	0.0 to 30 oz/cwt Sikaset NC (non-chloride accelerator)		

The above mixes are approved for use, contingent upon satisfactoiry site perfromance and continuous acceptability of all materials sources, by:

[signature] 5/4/10

ASST Concrete Engineering ~~Specialist~~ Date

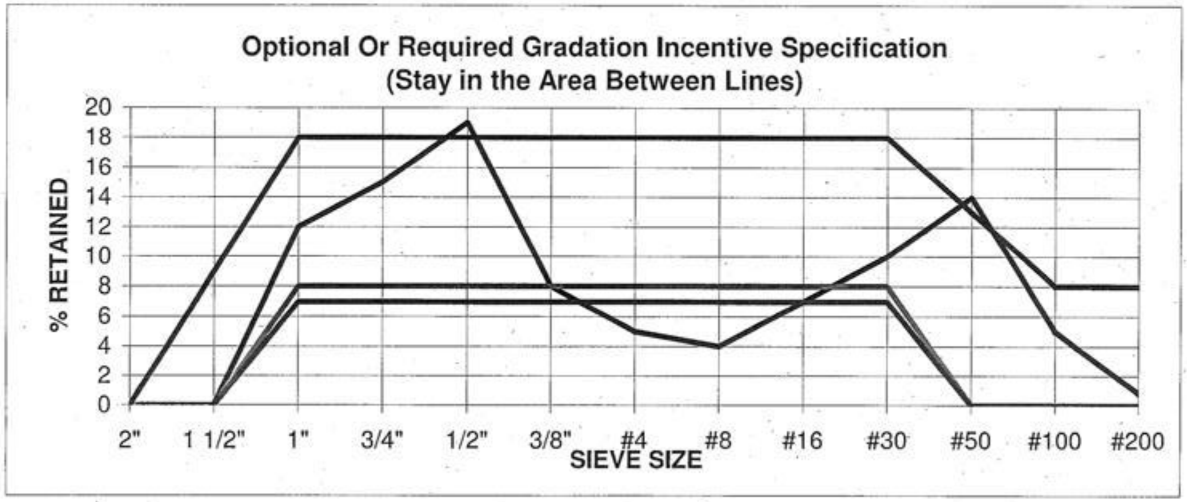
Comments: Attached gradation must be met

RCCMR JMF (8680-159)
Job Mix Formula

	CA #1	CA #2	CA #3	CA #4	FA #1	FA #2	TOTAL % PASSING	WORKING RANGE LIMITS	JMF WORKING RANGE		TOTAL % RETAINED
AGGREGATE SIZE	C. Sand	RC	1-1/2"								
PROPORTION, %	41.00%	31.00%	28.00%				100.00%				
2"	100.0	100.0	100.0				100	± 5	95	100	0
1 1/2"	100.0	100.0	100.0				100	± 5	95	100	0
1"	100.0	100.0	55.5				88	± 5	83	93	12
3/4"	100.0	99.0	5.8				73	± 5	68	78	15
1/2"	100.0	43.0	0.5				54	± 5	49	59	19
3/8"	100.0	15.0	0.3				46	± 5	41	51	8
#4	100.0	0.2	0.0				41	± 5	36	46	5
#8	90.6	0.0	0.0				37	± 4	33	41	4
#16	74.2	0.0	0.0				30	± 4	26	34	7
#30	49.9	0.0	0.0				20	± 4	16	24	10
#50	15.5	0.0	0.0				6	± 3	3	9	14
#100	1.9	0.0	0.0				1	± 2	0	3	5
#200	0.4	0.0	0.0				0.2	1.6% max	0.0	1.6	1

Workability Factor 37
(% passing #8)

Coarseness Factor 86
(% retained above 3/8" / % retained above #8)



JMF10-001

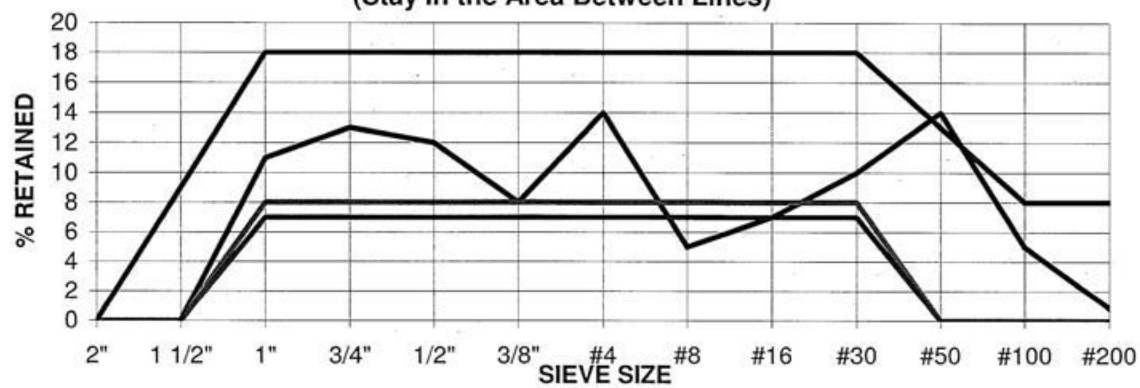
CHPMR60 JMF (8680-159)
Job Mix Formula

AGGREGATE SIZE	CA #1	CA #2	CA #3	CA #4	FA #1	FA #2	TOTAL % PASSING	WORKING RANGE LIMITS	JMF WORKING RANGE		TOTAL % RETAINED
	C. Sand	3/4"-	1-1/2"								
PROPORTION, %	40.00%	35.00%	25.00%				100.00%				
2"	100.0	100.0	100.0				100	± 5	95	100	0
1 1/2"	100.0	100.0	100.0				100	± 5	95	100	0
1"	100.0	100.0	55.5				89	± 5	84	94	11
3/4"	100.0	99.2	5.8				76	± 5	71	81	13
1/2"	100.0	68.3	0.5				64	± 5	59	69	12
3/8"	100.0	45.4	0.3				56	± 5	51	61	8
#4	100.0	5.3	0.0				42	± 5	37	47	14
#8	90.6	2.5	0.0				37	± 4	33	41	5
#16	74.2	0.0	0.0				30	± 4	26	34	7
#30	49.9	0.0	0.0				20	± 4	16	24	10
#50	15.5	0.0	0.0				6	± 3	3	9	14
#100	1.9	0.0	0.0				1	± 2	0	3	5
#200	0.4	0.0	0.0				0.2	1.6% max	0.0	1.6	1

Workability Factor 37
(% passing #8)

Coarseness Factor 70
(% retained above 3/8" / % retained above #8)

Optional Or Required Gradation Incentive Specification
(Stay in the Area Between Lines)



REQUEST FOR CONCRETE MIX APPROVAL

Requested by: Tom Schmit Phone: 651-319-2369
Firm Name: Aggregate Industries
Agency Enginner/Inspector: ____ S.P. 8680-159

Proposed Aggregate Sources

	CA #1		CA #2		CA #3	Sand	
Pit Number	73006		73006			71041	
Pit Name	Marietta		Marietta			Agg. Ind.	
Nearest Town	St. Cloud		St. Cloud			Elk River	
Size	1/2" W. Chips		3/8" W. Chips			M. Sand	
Sp. G. & Abs. (Provided by MN/DOT)	2.72	0.40%	2.72	0.40%		2.63	0.90%

Proposed Cementitious Sources

	Cement	Fly Ash	Other
Manufacturer/Distributor	Holcim	Headwaters	
Mill/Power Plant	STGBLMO	COCUNND	
Type/Class	I/II	C/F	
Specific Gravity	3.15	2.5	

Proposed Mix Designs

MN/DOT Mix Number	EACMR		
Water (lbs/C.Y.)	283		
Cement (lbs/C.Y.)	616		
Flyash (lbs/C.Y.)	109		
Other Cementitious (lbs/C.Y.)			
W/CM Ratio	0.39		
Sand (Oven Dry, lbs/C.Y.)	843		
CA #1 (Oven Dry, lbs/C.Y.)	1133		
CA #2 (Oven Dry, lbs/C.Y.)	843		
CA #3 (Oven Dry, lbs/C.Y.)	0		
Maximum Slump	3" Max		
% Air Content	7.00%		
Admix. # 1 (oz/100 # CM)	2.0 - 15.0 oz/cuyd Multi-Air 25		
Admix. # 2 (oz/100 # CM)	1.0 - 5.0 oz/cwt Sika 686		
Admix. # 3 (oz/100 # CM)	0 - 5.0 oz/cwt Delvo as needed for slump retention		

The above mixes are approved for use, contingent upon satisfactoiry site perfromance and continuous acceptability of all materials sources, by:

Maria Masten 4/1/2010
Concrete Engineering Specialist Date

Comments: attached composite gradation JMF 10-002 shall comply with the gradation requirements in supplemental agreement No. 1 Table 3137-3.

JMF10-002

EAC JMF (8680-159) (unprotected)
Job Mix Formula

	CA #1	CA #2	CA #3	CA #4	FA #1	FA #2					
AGGREGATE SIZE PROPORTION, %	M. Sand 30.00%	3/8" Chip 30.00%	1/2" Chip 40.00%				TOTAL % PASSING 100.00%	WORKING RANGE LIMITS	JMF WORKING RANGE		TOTAL % RETAINED
1 1/2"	100.0	100.0	100.0				100	± 5	95	100	0
1"	100.0	100.0	100.0				100	± 5	95	100	0
3/4"	100.0	100.0	100.0				100	± 5	95	100	0
1/2"	100.0	100.0	100.0				100	± 5	95	100	0
3/8"	100.0	100.0	94.0				98	± 5	93	100	2
1/4"	100.0	69.0	46.0				69	± 5	64	74	29
#4	100.0	35.0	19.0				48	± 5	43	53	21
#8	98.6	6.0	3.0				33	± 4	29	37	15
#16	93.5	2.0	1.0				29	± 4	25	33	4
#30	79.9	0.0	0.0				24	± 4	20	28	5
#50	37.9	0.0	0.0				11	± 3	8	14	13
#100	7.8	0.0	0.0				2	± 2	0	4	9
#200	1.4	0.0	0.0				0.4	1.6% max	0.0	1.6	2

Workability Factor 33
(% passing #8)

Coarseness Factor 46
(% retained above 3/8" / % retained above #8)

Optional Or Required Gradation Incentive Specification
(Stay in the Area Between Lines)